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Abstract

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THE PRE-PLIOCENE COURSE OF THE LOWER TENNESSEE RIVER AS DEDUCED FROM RIVER TERRACE GRAVELS IN SOUTHWEST TENNESSEE

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ABSTRACT

The texture and composition of gravel from Tennessee River terraces in southwestern Tennessee indicate a progressive change from quartzose Appalachian sources to cherty Highland Rim sources. The change from quartz dominated to chert dominated gravels may mark the breaching of the Ft. Payne Chert (Miss.) during the rejuvenation of the Nashville Dome (possibly 5.0 mya, late Miocene – early Pliocene). Comparison of the Tennessee terrace gravels with those of terraces and the Claiborne Formation (middle Eocene) in the Hatchie River Valley to the west suggest that an ancestral Tennessee River, with Appalachian sources flowed westward through the Hatchie River Valley prior to the breaching of the Ft. Payne Chert.

INTRODUCTION

Near Pickwick in southwest Tennessee, the Tennessee River makes an abrupt right angle bend where it changes from a westward to an anomalous northward course and flows over hard Paleozoic carbonate and cherts of the westernmost extension of the Highland Rim (Figure 1). Most streams in the area flow south towards the Gulf of Mexico or west towards the Mississippi River where they cross relative soft Cretaceous and Cenozoic sediments of the Gulf Coastal Plain. Brown (1967), noting a series of southward trending gravel ridges in Mississippi, proposed that the ancestral Tennessee River flowed south to the Gulf of Mexico. Ishordring (1983) suggested that such a course during the Miocene could account for heavy mineral assemblages and chert in the Ecor Rouge and Citronelle gravels along the eastern Gulf Coast. Kaye (1974) proposed that Plio-Pleistocene ice dams on the Tennessee River caused overflow to the south or west. Milici (1968) proposed that the present course of the Tennessee River is due to stream capture by a smaller northward flowing stream. The course or courses ancestral of the Tennessee River in west Tennessee thus remains uncertain.

A series of graveliferous fluvial terraces associated with the Tennessee River are exposed in southwest Tennessee, just north of the bend at Pickwick (Figure 1). These terraces are mapped as Qfl (fluvial deposits) on quadrangle and state maps (Russell, 1964, 1967, 1968, Russell and others, 1970, 1971 1972; Wilson, and others, 1982; and Miller, and others) and are discussed by Russell and Parks, (1975) and Russell (1979). The Terraces are strategically located relative to proposed course changes in the ancestral Tennessee River and are not found north of the study area in the modern Tennessee Valley. Graveliferous terraces and Claiborne (Eocene) gravels are also found considerably west of the modern Tennessee Valley, along the small underfit, westward trending Hatchie River Valley whose headwaters are within three miles of the westernmost Tennessee River terraces and which form a continuation of the west – northwest trend of the modern Tennessee River east of the study area (Figure 1). Topography suggests that the Hatchie River Valley may be a former course of the Tennessee River. The Hatchie gravels are therefore included in the study.

The purpose of this study is to ascertain if stratigraphic and petrologic studies of these terrace gravels can provide evidence concerning course and provenance changes for the ancestral Tennessee River.

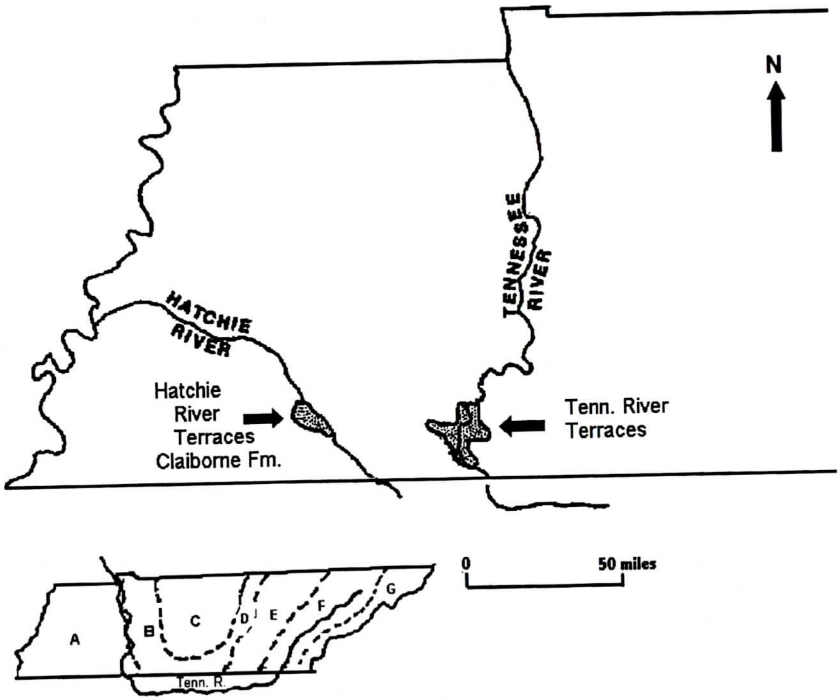

Figure 1. Designated on insert A = Gulf Coastal Plain; B = Western Highland Rim; C = Central basin of Nashville Dome; D = Eastern Highland Rim; E = Cumberland Plateau; F = Valley & Ridge; G = Crystalline Appalachian.

GEOLOGIC SETTING

The study area is situated along the boundary of the western Highland Rim of the Nashville Dome and the Mississippi Embayment section of the Gulf Coastal Plain in southwest Tennessee. The Tennessee River initially flows through the crystalline Appalachians, the valley and ridge and Cumberland Plateau provinces which contain a large variety of source rocks and contributes quartz, quartzite and lesser amounts of rock fragments. The Tennessee River then flows westward across the Highland Rim of the Nashville Dome before entering the study area. Silurian to Mississippian carbonates and cherts outcrop in the Highland Rim, and provide a source for chert. Cretaceous to Recent sands, silts, clays, and minor gravels underlie the Mississippi Embayment, to the west of the study area.

Tennessee River terrace deposits consist of gravels that grade upward into sands and silts. (Russell and Parks, 1975). The gravel consists of pebbles of chert with lesser amounts of quartz, quartzite, limestone, sandstone and igneous pebbles. The chert is yellowish-brown to white, tripolitic and angular to subround. Quartz, quartzite and sandstone pebbles tend to be smaller in size than chert and very well rounded (egg shaped). Gravels tend to be massive to indistinctly cross stratified. Some gravels have imbrication and a few gravel beds are graded. Bedding is lenticular and discontinuous with common channels and scoured surfaces. Matrix consists of quartz sand mixed with reddish silt and clay. Medium to coarse, moderate to poorly sorted, highly quartzose crossbedded sands are interbedded within gravels. Sand-gravel contacts are sharp. Most deposits contain large amounts of diagenetic iron oxide, which colors the terrace brick red or reddish brown color, and also cements many layers into ferruginous conglomerates. Russell and Parks (1975) report terraces with thicknesses up to 70 feet. At some locations, the upper 20 to 30 feet consists of sands, silts, and clays that in other locations have been removed due to erosion.

The terraces lack fossils and are difficult to date. They overlie Upper Cretaceous sediments including the McNairy, Coon Creek, Demopolis, and Coffee formations west of the Tennessee River and the Cretaceous Eutaw formation east of the Tennessee River and are thus younger than Upper Cretaceous.

TERRACE CLASSIFICATION

Russell and Parks (1975) reported terrace elevations of 700 feet above mean sealevel (MSL), and above and at 580 feet (MSL). Russell (1979) reported elevations of 600 feet for the western most terraces at Michie, 500 feet for terraces west of Chambers Creek, and 415 feet for those underlying Shiloh.

The present study defines the following terraces from oldest (topographically highest) to youngest (topographically lowest):

1. **Qfl$_1$** Small scattered erosional remnant of terraces with tread elevations over 700 feet (MSL) are found east of the Tennessee River.
2. **Qfl$_2$** Remnants of a terrace with tread elevations of 600 to 620 feet (MSL) are found east of the Tennessee River, with one small remnant west of the river. This terrace is more extensive than Qfl$_1$.
3. **Qfl$_3$** (Michie - Pebble Hill Terrace) the tread of this terrace ranges between 560 to 580 feet (MSL). These gravel deposits cap ridges and are the western most terraces in the study area. Terraces at this level also occur along the west side of Horse Creek, east of the Tennessee River. Minor remnants are found east of Savannah and south of Shiloh.
4. **Qfl$_4$** (Chambers Terrace) This terrace, with a tread that averages 500 feet (MSL), is extensive west of the Tennessee River where it forms a relatively flat surface. Small remnants may be present east of Pickwick Village (Pickwick Quadrangle), east of Savannah (Savannah Quadrangle) and west of Horse Creek.
5. **Qfl$_5$** (Shiloh Savannah Terrace) This is the most extensive terrace in the study area. It underlies Shiloh Battlefield and the City of Savannah. Tread elevations range from 420' to 480'.

A schematic "staircase" sketch showing topographic relationships between terraces are shown in Figure 2.

In addition, terraces and high level fluvial deposits (designated Qfl$_H$) and gravels from the Eocene Claiborne Formation (Tc) are found in the Hatchie River Valley southeast of Bolivar (Figure 1) (Jones & Sykes, 1973, Parks, 1992, Parks & Sykes 1968a, 1968b, Parks & Wilson, 1974, Self, 1997). These terraces consist of lenses, stringers, and beds of quartzose gravels in poorly to well sorted reddish quartz sands. Parks (1992) differentiated four terraces and high level fluvial deposits along the southwestern side of the Hatchie Valley. The terraces consist of sand with scattered gravel. The gravels are well rounded to quartz, quartzite and sandstone pebbles. The high-level fluvial deposit gravels are similar but are more concentrated.

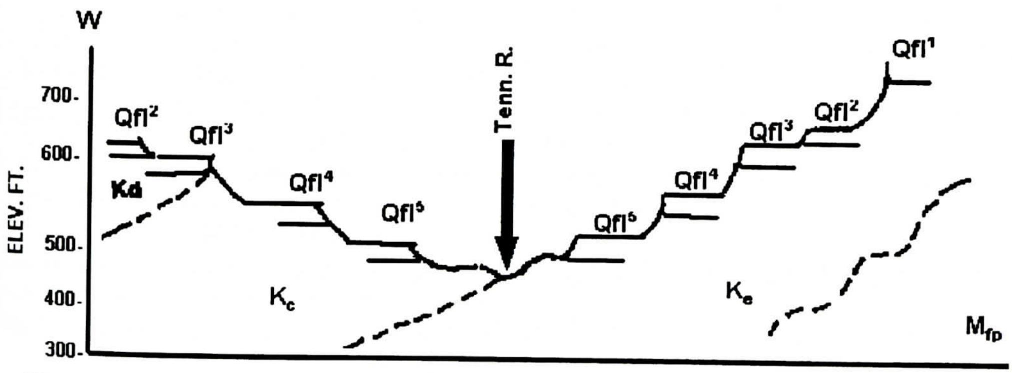

Figure 2. Schematic "stairstep" diagram of Tennessee River Terraces

Table I. Topographic relationship of Hatchie Terraces (mod. from Parks, 1992)

Geologic unit	Altitude of tops and bases above sea level, in feet	Remnant thickness, in feet
High Level Fluvial Deposits	600	
		40
	560	
Terrace Deposit "D"	535	
		45
	490	
Terrace Deposit "C"	495	
		50
	445	
Terrace Deposit "B"	450	
		60
	390	
Terrace Deposit "A"	385	
		40
	345	

Table II. Location and Description of Samples.

Sample	Terrace	Quadrangle	Tennessee Coordinates	Elev. of tread outcrop	Notes
1A	Qfl_5	Pittsburg Landing	312,200 N 1,306,200E	500/505	coarse unit near base of face
1E	Qfl_5	Pittsburg Landing	312,200N 1,306,200E	500/505	eastern face of pit
2A	Qfl_3	Michie	263,600 N 1,271,500E	570 ft/600	large pebbles - gravel _____ layer
2C	Qfl_3	Michie	263,600N 1,271,500E	570 ft/600	gravely-sd to finer gravel
3	Qfl_3	Michie	261,600N 1,271,300E	570 ft/590	5ft exposure - little structure
4	Qfl_3	Michie	252,800N 1,274,900E	578/610 ft	5 ft. exposed - indurated with iron cement
5	Qfl_4	Counce	235,300N 1,302,200E	510/515	huge channel-sampled near base
6A	Qfl_4	Counce	237,000N 1,307,500E	510/540	possible channel at west end of large pit
6B	Qfl_4	Counce	237,000N 1,307,500E	510/540	southeast corner of pit
7	Qfl_4	Counce	258,800N 1,297,200E	500/510	small outcrop-stringers of cobbles
8	Qfl_5	Counce	253,300N 1,309,700E	430/440	poor overgrown pit with 5 ft. exposed, cobbles at base
9	Qfl_4	Counce	242,500N 1,314,900E	520/525	finning upward sequence, coarse pebbles→fm. pebbles
9A	Qfl_4	Counce	242,500N 1,314,900E	530/525	similar to 9
10	Qfl_3	Pickwick	239,800N 1,330,300E	550/580	near base of face
10A	Qfl_3	Pickwick	239,800N 1,330,300E	550/580	Top unit x-bed

Table II. Location and Description of Samples, continued.

Sample	Terrace	Quadrangle	Tennessee Coordinates	Elev. of tread outcrop	Notes
10C	Qfl_3	Pickwick	239,800N 1,330,300E	550/580	Northeast face of pit possible channel (?)
11	Qfl_5	Counce	262,100N 1,324,000E	470/480	fine x-bedded gravel
11A	Qfl_5	Counce	262,100N 1,314,000E	470/480	coarser gravel at base
12	Qfl_5	Hooker's Bend	363,050N 1,331,500E		5 ft. of exposed massive gravel
13A	Qfl_5	Thurman	372,000N 1,336,000E	420/445	finning upward with sand lenses, east end of pit
13B	Qfl_5	Thurman	372,000N 1,336,000E	420/445	coarser than 13A, west end of pit
14A	Qfl_4	Savannah	311,500N 1,351,200E	510/520	sampled 2 ft above base, finning and sandy upwards
15A	Qfl_2	Savannah	301,350N 1,357,150E	580-600/660	fine pebble - granites v. sdy
15B	Qfl_2	Savannah	301,350N 1,357,150E	580-600/660	coarser than 15A, x-bedded
16	Qfl_2	Savannah	291,450N 1,351,750E	620/660	small outcrop - sdy gravel
17A	Qfl_5	Pittsburg Landing	312,000N 1,312,000E	450/470	X-bed gravel & sd.
17B	Qfl_5	Pittsburg Landing	312,000N 1,312,000E	450/470	massive gravel
29A	Qfl_1	Loweryville	260,000N 1,368,000E	700/730	small road cuts on west
29B	Qfl_1	Loweryville	261,000N 1,366,000E	700/720	Side of Hwy. 60 – gravel dispersed in sand
40	Qfl_H	Heron	287,300N 1,110,750E	440/480	poor highly weathered pit with scattered gravel
41	T_c	Bolivar East	239,250N 107,800E	500/515	very old weathered pit with scattered gravel
42	T_c	Hebron	300,000N 1,107,500E	520/560	very old weathered pit with scattered gravel

Table III. Textural Data Gravels

Sample #	Terrace	Mean Grain Size	Standard Deviation	Skewness	% Gravel	% Gravel <-4.6Ø
29A	Qfl_1	-3.10Ø	1.39Ø	+0.025	-	-
29B	Qfl_1	-2.98Ø	1.18Ø	+0.04	-	-
15A	Qfl_2	-2.86Ø	1.12Ø	+0.31	57	17
15B	Qfl_2	-2.93Ø	1.05Ø	+0.09	54	7
16	Qfl_2	-3.38Ø	1.21Ø	+0.02	79	16
3	Qfl_3	-4.23Ø	1.01Ø	-0.61	82	53
4	Qfl_3	-3.85Ø	1.00Ø	-0.47	70	18
10	Qfl_3	-3.66Ø	1.00Ø	-0.19	77	9
10A	Qfl_3	-3.02Ø	1.08Ø	+0.33	78	22
10C	Qfl_3	-3.78Ø	1.23Ø	-0.31	79	32
2A	Qfl_3	-4.02Ø	0.74Ø	-0.43	85	15
2C	Qfl_3	-2.58Ø	0.93Ø	-0.20	47	4
7	Qfl_4	-3.66Ø	1.01Ø	-0.15	81	12
14A	Qfl_4	-3.25Ø	1.08Ø	+0.03	80	10
5	Qfl_4	-4.20Ø	1.06Ø	-0.43	83	46
6A	Qfl_4	-3.92Ø	0.98Ø	-0.30	74	25
6B	Qfl_4	-3.98Ø	1.31Ø	-0.39	72	43

Table III. Textural Data Gravels, continued.

Sample #	Terrace	Mean Grain Size	Standard Deviation	Skewness	% Gravel	% Gravel <-46Ø
9A	Qfl_4	-4.42Ø	0.98Ø	-0.42	92	53
1A	Qfl_5	-3.97Ø	0.91Ø	-0.12	79	28
1E	Qfl_5	-4.23Ø	1.01Ø	-0.48	79	44
8	Qfl_5	-4.08Ø	1.23Ø	-0.34	80	43
11	Qfl_5	-3.63Ø	1.27Ø	-0.15	69	22
11A	Qfl_5	-4.27Ø	1.05Ø	-0.52	87	57
17A	Qfl_5	-4.20Ø	1.17Ø	-0.46	89	89
17B	Qfl_5	-4.60Ø	0.89Ø	-0.52	88	66
13A	Qfl_5	-3.78Ø	0.00Ø	-0.36	74	18
13B	Qfl_5	-3.83ØØ	1.06Ø	-0.28	88	31
40	Qfl_H	-3.03Ø	0.94Ø	+0.4	-	-
41	T_c	-3.12Ø	0.77Ø	+0.15	-	-
42	T_c	-2.82Ø	1.16Ø	-0.09	-	-

Table 4. Compositional Data Gravels.

Sample	Terrace	% Chert	% Quartz	% Rock Fragment
29A	Qfl_1	0	87	13
29B	Qfl_1	0	84	16
15A	Qfl_2	78	14	8
15B	Qfl_2	72	14	14
16	Qfl_2	47	37	15
3	Qfl_3	75	8	17
4	Qfl_3	87	8	3
10	Qfl_3	82	13	9
10A	Qfl_3	80	11	5
10C	Qfl_3	78	10	12
2A	Qfl_3	73	15	12
2C	Qfl_3	74	20	6
7	Qfl_4	78	5	16
14A	Qfl_4	78	7	15
5	Qfl_4	57	3	40
6A	Qfl_4	83	13	4
6B	Qfl_4	70	11	19
9	Qfl_4	88	5	7
9B	Qfl_4	83	9	8
1A	Qfl_5	80	7	13
1E	Qfl_5	77	12	11
8	Qfl_5	84	13	3
11	Qfl_5	71	10	19
11A	Qfl_5	70	16	14
17B	Qfl_5	77	8	15
13A	Qfl_5	81	3	16
13B	Qfl_5	88	4	8
40	Qfl_H	0	74	25
41	T_c	0	89	11
42	T_c	0	92	8

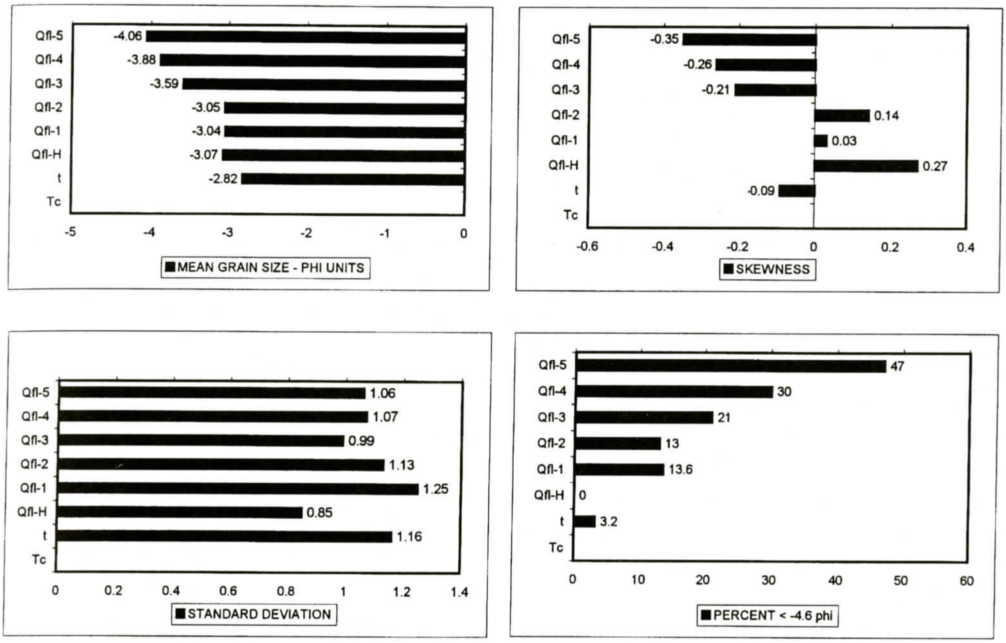

Figure 3. Comparison of average textural characteristics of terrace gravel from terraces of western Tennessee.

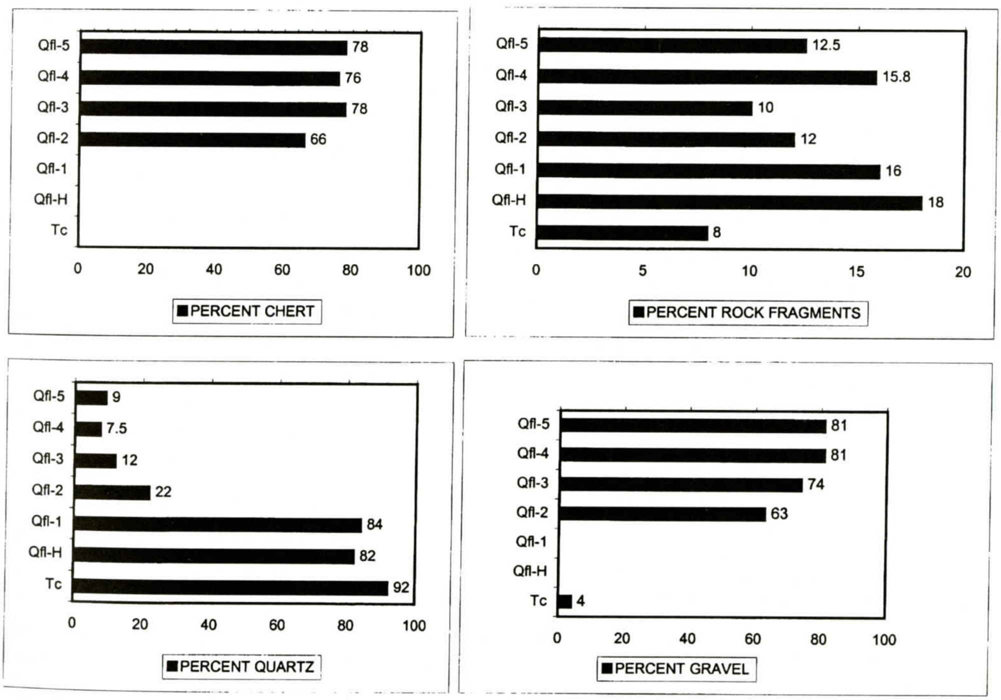

Figure 4. Comparison of average composition of terrace gravel fraction from western Tennessee.

Parks (1992) suggest that the terraces were derived from high level fluvial deposits and they in turn were derived from similar Claiborne gravels. Topographic relationships are shown in Table I (Parks, 1992). The Qfl-H samples were taken from terraces "C" or "D."

METHODS

Twenty-seven samples were collected from eighteen localities, most from the walls of gravel pits.

Samples were then sieved and standard textural parameters (graphic mean grain size, inclusive graphic standard deviation, inclusive graphic skewness) (Folk 1968) were calculated, as well as the percent gravel and the percent clasts coarser than –4.6∅ (26 mm). Results are reported in both phi units (Folk, 1968) and their millimeter equivalents. Each size fraction was examined under a binocular microscope and chert, quartz, and rock fragment percentages estimated.

TEXTURAL AND COMPOSITIONAL CHARACTERISTICS

Tennessee River gravel fractions have mean grain sizes in the medium pebble range (-2.86∅ to -4.42∅ or 7mm to 23mm), are moderately to poorly sorted (0.74∅ to 1.31∅), and are negatively skewed (Table III). Qfl_2 – Qfl_5 gravel composition is dominated by yellow-brown chert with secondary amounts of white chert, quartz and rock fragments, while Qfl, and the Hatchie terraces are quartz dominated with secondary rock fragments and little chert (Table III & IIV). Gravel percentage range from 47% to 92% by weight with most samples between 75% and 89% (Table IV). Pebbles and cobbles coarser than -4.6∅ (> 26mm) vary widely from 4% to 89% by weight.

Averages for mean grain size, skewness, gravel percentage, chert and quartz percentages for each terraces show consistent differences between terraces in the gravel fractions which are as summarized below (Figures 3,4):

1) Average mean grain size decreases with increasing age
2) Qfl_2, Qfl_1, and Qfl_H have similar mean grain sizes
3) No trend is shown in sorting
4) Skewness becomes less negative and then positive with increasing age with the exception of Tc, which is negatively skewed
5) Gravel and coarse gravel (<-4.6∅ or > 26mm) percentages decrease with increasing age
6) Chert content decreases and quartz content increases with increasing age
7) Qfl_1, Qfl_H and Tc consists of well rounded quartz pebbles with little or no chert while Qfl_2 – Qfl_5 are dominated by chert
8) Hatchie terraces (Qfl_H) (and Claiborne (Tc)) gravel fractions are lithologically similar to Qfl_1 gravels and lack the chert associated with Qfl_2 – Qfl_5 gravels

INTERPRETATIONS AND CONCLUSIONS

Finer grain sizes, increasing winnowing (skewness), decreasing in gravel and gravel coarser than -4.6∅ (> 26mm) percents as well as a dramatic increase in quartz and a decreasing chert content indicate a change in provenance and/or increasing distance of transport with increasing age. Quartz and quartzite are derived from the distant Appalachians while chert is primarily derived locally from the Mississippian Ft. Payne and Devonian Camden (recycled through the Cretaceous Tuscaloosa formation) formations of the Highland Rim. The data suggests a progressive change from distant Appalachian sources in the older terraces to local Highland Rim sources in progressively younger terraces. The oldest terrace (Qfl_1), the Hatchie terraces (Qfl_H) and the Claiborne gravels (Tc) are dominated by quartz with very little chert and thus have Appalachian sources with almost no impact from the Highland Rim.

Based on calculated isostatic adjustments due to erosion on a no load surface (base of Chattanooga shale), Reesman and Stearns (1989) suggest that the Nashville Dome was rejuvenated and that the Ft. Payne over the crest

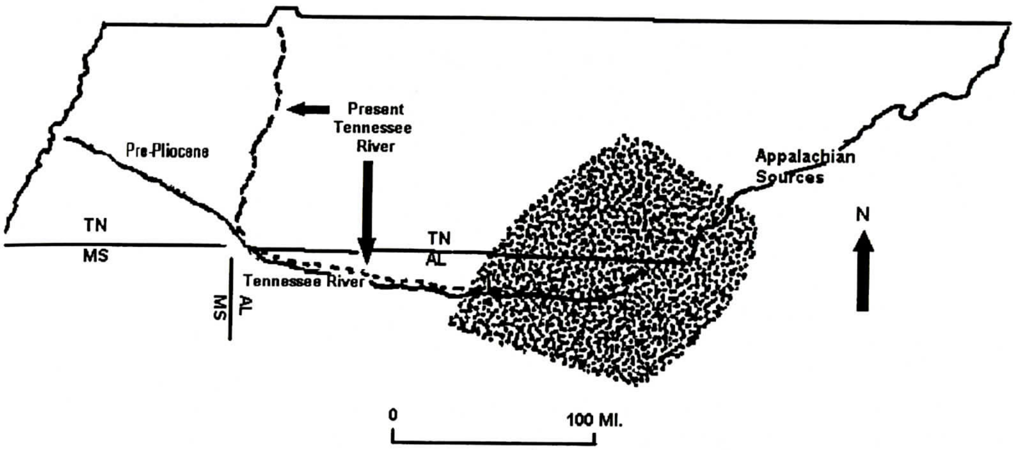

Figure 5. Map showing Pre-Pliocene Tennessee River. Solid line shows the approximate course of the Pre-Pliocene Tennessee River and dashed lines the present course.

of the Dome may have been breached approximately 5 million years ago (late Miocene – early Pliocene) which could have caused a flood of cherty gravels in the Gulf Coast and Mississippi Embayment (Self, 1993). Most of Qfl_1, and much of Qfl_2 have been removed by erosion due to this uplift.

The quartz rich, chert poor Qfl1 and the Hatchie gravels were deposited before the unroofing of the Ft. Payne formation (possibly late Miocene – early Pliocene). Chert rich Qfl_2 – Qfl_5 terraces progressively reflect the rejuvenation of the Nashville Dome and the breaching of the Ft. Payne and are therefore younger than the breaching. The size and trend of the Hatchie Valley as well as lithological similarities of the Qfl_1 and the Hatchie gravels suggest that a large river, presumably ancestral Tennessee River, flowed from Appalachian sources westward through the Hatchie River Valley prior to the breaching of the Fort Payne and possibly as early as middle Eocene (Claiborne deposition) (Figure 5).

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PALYNOLOGY AND PALEOECOLOGY OF A WOOD-BEARING CLAY DEPOSIT FROM DEEPSTEP, GEORGIA

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ABSTRACT

A wood-bearing clay deposit, believed to represent an ancient beaver dam or lodge, was discovered in a kaolin mine near Deepstep, Georgia. The pieces of wood, which were radiocarbon dated at >47,470 years of age, were typically short branches (about 30 cm). Many had faceted or bevelled ends, none of them had bark, and they were mixed with clay, silt, and well-rounded pebbles. A number of thin branches with bevelled ends were perpendicular to bedding in sediments that lay some distance from the main accumulation of wood. These are interpreted to represent the food cache of the ancient beavers. Several wood samples were identified as Taxodiaceae, and probably are from cypress, *Taxodium* sp. Three pollen samples contained a variety of tree, shrub, and herbaceous pollen types, including *Alnus*, *Liquidambar*, *Pinus*, *Picea*, *Quercus*, *Taxodium*, *Gordonia*, *Typha*, and sedges. The assemblages of both warm- and cool-climate taxa suggest that the ranges of the northern and southern plants overlapped at the time of deposition.

INTRODUCTION

On October 18, 1996, samples of clayey, wood-bearing sediment were collected from the highwall of the Boatright Mine, near Deepstep, Washington County, Georgia. The samples were analyzed for pollen and samples of wood were identified and dated. The sediments and, particularly, bevelled pieces of wood that had accumulated in a dense mass suggest that the sediments represent a beaver lodge or a beaver dam and associated pond sediments. Furthermore, pieces of wood that had bevelled ends and which were preserved perpendicular to bedding are believed to have been part of the ancient beavers' store of food. This report describes the procedures used to analyze the samples, and presents the results of our investigation.

LOCATION AND GEOLOGY OF THE STUDY AREA

The Boatright Mine is located in Washington County, in central Georgia (Figure 1). Washington County lies within the Georgia kaolin belt, an area lying along the Fall Line and extending

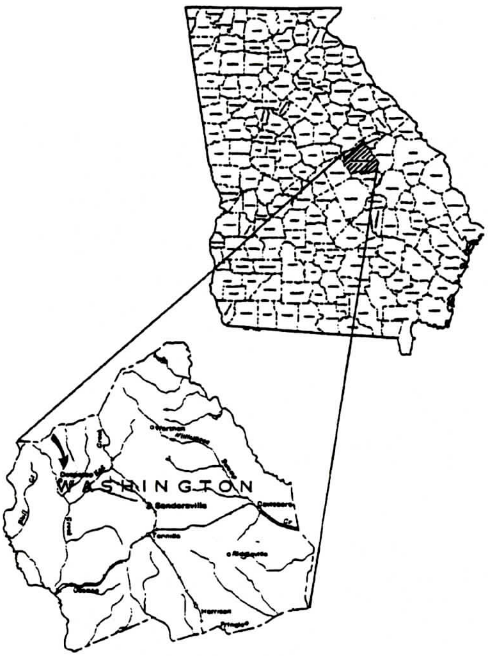

Figure 1. Location of the Boatright Mine. The small arrow indicates the village of Deepstep.

from South Carolina to Alabama. The kaolin belt is characterized by the presence of some of the world's most extensive deposits of kaolinite, a white clay that is used extensively in paper coating. The kaolin beds of central Georgia were deposited in sediments of Cretaceous to Eocene age (roughly 70 and 40 million years old, respectively); kaolin-bearing strata exposed at the Boatright Mine are most likely to be a part of the Eocene Huber Formation. Overlying material is younger, but an absolute age has not been established for it, as is explained below.

DESCRIPTION OF THE SAMPLES

The horizon from which we collected samples consisted of a lens of dark clay with abundant branches that had accumulated on top of the Eocene Huber Formation. Above the clay lens lie about 7 m of cross-bedded quartz-dominated sands (Figures 2 and 3). The lens was nearly 5 m wide and about 0.5 m thick; at several points in the clay lens well-rounded pebbles of quartz were noted. The wood in the clay lens was dark brown, humified, and waterlogged. Though the wood was dark, none of it appeared to have been charred. Most of the branches lay parallel to the bedding plane of the clay, a few lay at an angle to bedding, and many smaller pieces of wood were perpendicular to bedding. All of the pieces of wood were bare of bark, and one large piece had a faceted end with a prominent central ridge toward which the facets were oriented. All of the small pieces of wood which stood perpendicular to bedding had at least one faceted or bevelled end. Although some of the branches were compressed parallel to bedding, most were nearly circular in cross-section.

The wood-bearing clay layer lay atop a prominent, well-cemented limonite horizon. The limonite is considered to represent an erosional surface (disconformity) which separates the Huber Formation from the much younger sediments that overlie the clay lens. Where the clay lens was thickest, the limonite layer was very hard and resisted breaking even with a rock hammer. Lateral to the clay lens, where the clay and wood accumulation was much thinner, the limonite was softer and less well developed.

PROCESSING TECHNIQUE

Samples were collected for three types of analysis- palynological, wood identification, and radiometric age determination. The three pollen samples were removed from organic-rich portions of the clay lens, generally in the vicinity of the thickest bed of the clay (Figure 3). All were dominated by clay and were treated identically for extraction of pollen, spores, and other microscopic organic particles. The procedure that was followed is a modification of the process recommended by Traverse (1988) for extracting pollen and spores from silty and clayey sediments, and included treatment with 10% KOH, 10% HCl, and 52% HF. At least 300 identifiable pollen/spores were counted for each sample. Notes were also made as to the general characteristics of the insoluble residues on the slides, and the presence or absence of features such as microscopic algae was recorded.

Figure 2. Highwall of the mine; geologists are observing the wood-bearing clay layer.

Figure 3. View of the dark clay layer which bore the concentration of wood. Pick handle is about 64 cm long.

Ten wood samples were collected for identification. Six were taken from the dam/lodge, and four from the vertically standing sticks. The pieces that were identified were removed from large specimens, wrapped in plastic wrap while still moist, and sent to Lee Newsom, Center for Archaeological Investigations, Southern Illinois University. The remaining portion of each specimen was frozen and is kept in the palynology laboratory at Georgia Southern University.

A piece of wood was washed in distilled water, dried at 100 degrees Celsius, and sent to BETA Analytic for radiocarbon analysis.

RESULTS OF THE ANALYSES

The pollen flora is diverse, but it is dominated by just a few taxa (Table 1). There are 39 taxa represented, including 26 trees and shrubs, 13 taxa of herbaceous plants (including 1 fern, 1 moss, 1 lycopod), and 2 types of algal cysts. The most abundant pollen type was *Pinus* (pine), which comprised 40.1% of one sample. The second most abundant taxon in any sample was *Taxodium* (cypress), while *Alnus* (alder) was third most abundant at 15.9% of one sample, and *Quercus* (oak) was fourth at 8.2% of one sample. There were two boreal or cold-temperate genera [*Picea* (spruce) and *Tsuga* (hemlock)], and one subtropical genus [*Gordonia* cf. *lasianthus* (L.) Ellis, loblolly bay]. Some taxa were distinctly wetland forms [*Taxodium, Nyssa* (tupelo), *Itea* cf. *virginica* L. (Virginia willow), *Sagittaria* (arrowhead), and *Typha angustifolia* L.(cattail)] whereas others were upland, hardwood forest plants [*Carya* (hickory or pecan), *Quercus*, *Corylus* (hazelnut), *Fagus* cf. *grandifolia* Ehrh. (beech), and *Liquidambar* cf.*styraciflua* L. (sweet gum)]. Grasses were nearly absent from the samples (constituting 0.56%, 0.56% and 0.61% of the three samples) and other ground-cover taxa, such as ferns and sedges, were rare.

A particularly large, faceted piece of wood (Figure 4) is *Pinus*, belonging to section diploxylon (i.e., hard pine, more specifically the *taeda* wood-anatomical group). There are some northern species such as *Pinus resinosa* whose wood anatomy resemble that of this specimen, but the tree that produced this stem/branch could also have been affiliated with the "southern hard" or "yellow" pines that live in central Georgia today.

All other identified wood specimens belong to the Taxodiaceae, and are almost certainly cypress, *Taxodium* sp. Some pieces displayed unusual anatomical traits, such as one which had false growth rings, suggesting that the tree grew under some kind of environmental stress. Yet another specimen seemed to be composed of cypress knee/root wood because the tracheids displayed the very distinctive structure of root wood. An alternative hypothesis is that it was a piece of stem wood from a tree that had been subjected to overly deep water. That kind of stress causes root-like wood formation in normal stems (Yamamoto, 1992). Finally, the vertical sticks were all identified as *Taxodium* root or knee wood.

Table 1. Taxa of pollen, spores, and algal cysts (*Ovoidites* and *Pseudoschizaea*) found in three Boatright samples, identified as 1p, 2p, and 3p Relative abundances are expressed as percentage of total pollen, spores, and cysts found in each sample.

	1p	2p	3p
1.*Acer rubrum*	1.1	.84	
2. *Alnus* sp.	15.9	9.5	10.4
3. *Ambrosia* sp.		.28	
4. Asteroideae	.28	.56	
5.*Betula* sp.	.56	.28	.61
6. *Botrychium* sp.	.28		
7. *Carya* sp.	.28	.84	1.2
8. Caryophyllaceae	.56	.56	1.2
9. *Castanea* sp.		.28	.61
10. *Celtis* sp.		.28	
11. Chenopodiaceae/ Amaranthaceae		.28	
12. Cornaceae			.30
13. *Corylus* sp.		.84	1.5
14. Cyperaceae	.56	1.9	3.0
15. Cyrillaceae	.56	.28	
16. *Decodon verticillatus*		.56	
17. Ericaceae	.84		.91
18. *Fagus grandiflora*	.84	1.7	2.1
19. *Fraxinus* sp.		.84	.61
20. *Gordonia lasianthus*	1.4	1.1	.61
21. *Ilex* sp.	.56	.28	.30
22. *Liquidambar styraciflua*	2.5	2.2	3.3
23. *Lycopodium* sp.	.28		.30
24. *Nyssa* sp.	1.1	.28	.91
25. *Ostrya/Carpinus*	1.4	.30	.30
26. *Ovoidites ligneolis*	.28		
27. *Picea* sp.	3.1	2.5	4.9
28. *Pinus* sp.	35.2	40.1	33.8
29. Poaceae	.56	.56	.61
30. *Polygonum* sp.			.30
31. *Pseudoschizaea rufina*	.28		
32. *Quercus* sp.	7.3	6.5	8.2
33. *Sagittaria* sp.		.28	
34. *Salix* sp.	.56	.28	
35. *Sphagnum* sp.		.28	
36. *Taxodium* sp.	12.7	16.6	14.0
37. *Tsuga* sp.	2.5	.84	.30
38. *Typha angustifolia*	1.1	2.2	3.9
39. *Ulmus* sp.	.28	.28	
40. unknowns	7.0	3.6	5.5

The wood sent for radiocarbon analysis was dated at >47,740 yr. B.P. (Beta-98688). Such a date is beyond the limit of radiocarbon age resolution, and we consider the sample to be undateable in the finite sense. The fact that no extinct taxa of pollen or spores were encountered suggests, however, that the deposit is Pleistocene. This interpretation is supported by the observation that the wood is humified rather than coalified, and, consequently, it seems more likely to be of Quaternary age than Tertiary. In order to make floristic comparisons to other deposits from the southeastern U.S. we have, therefore, made the assumption that the Boatright deposit is of Pleistocene age, though we cannot state what part of the Pleistocene it represents.

DISCUSSION

Based upon the sedimentological and palynological analyses, we believe the Boatright samples were deposited in a pond or stream within which waterlogged pieces of wood had accumulated. The presence of both wood and well rounded pebbles in the clayey sediment would normally suggest that the waterway was subject to periodic floods which were capable of moving rather large particles, but an alternative hypothesis, which relates to the presence of beavers at the site of deposition, is presented below.

The vegetation of the area surrounding the site of deposition was a mixture of upland and lowland, and northern and southern species. The most abundant pollen type is pine, which is not unexpected. Pines tend to dominate pollen assemblages throughout the Southeast (Watts, 1969; Delcourt and Delcourt, 1985). The abundance of oak pollen (7.3%, 6.5%, and 8.2%) falls within the range one might expect for samples from the southeastern U.S. (Webb and Bernabo, 1977), but the numbers are quite low compared to the values that, for example, represent Late Pleistocene strata from that region (Watts and Hansen, 1988; Grimm and others, 1993). Oak pollen percentages in the Boatright samples suggest that oak trees were not common at or near the site of deposition.

Plants which are interpreted to have actually grown at the site of the wood and clay accumulation were cypress, loblolly bay, tupelo, and alder. This interpretation is based upon the presence of cypress wood at the site of deposition, the pollen dispersal potential of *Gordonia* and *Nyssa* (Cohen, 1975; Rich and Spackman, 1979), and the large amount of alder pollen that typifies the Boatright sediments. This is an unusual combination of plants because cypress, tupelo, and loblolly bay are typical of Southern swamps whereas alder is more typical of cooler climates. As Small (1933) and Radford and others (1968) point out, *A. crispa* (*rugosa*) is widespread along streams and in swamps in the southeastern U.S., but its presence in cypress-tupelo bay environments is rather limited. Wright and Wright (1932) conducted a very comprehensive plant survey of the Okefenokee Swamp, for example, and showed that occurrences of *Alnus* in the Okefenokee Swamp and its vicinity are very restricted. Rich (1979) determined that it's pollen always constituted less than 1% in his many samples from the Okefenokee Swamp, while Frey (1953) found only very small amounts of *Alnus* in surface and near-surface samples from various sites in North Carolina. Watts (1970, 1973, 1980) encountered less than 5% of *Alnus* in his samples, and, summing the results of analyses of 19 southeastern forest sites, Davis and Webb (1975) determined that the mean value for *Alnus* among just arboreal pollen types was 1.9%. The Boatright pollen assemblage is clearly unusual, and the cypress-tupelo-loblolly bay forest with alder understory has no modern analog.

The paleoenvironmental interpretation is that, at the time of deposition, the climate in central Georgia was probably slightly cooler than at present, in order to support the combination of alder and the southern wetland trees. The cypress and tupelo, though much more common in the American South, are both abundant in the Mississippi Valley as far north as southern Illinois and Indiana, and *Nyssa* grows as far north as southern Ontario (Gleason and Cronquist,1963)]. However, *Gordonia* is a distinctly southern plant which has little tolerance for cold weather.

Among the plants whose ranges seem to be in conflict, and which are found in the Boatright samples are the following (range data from Gleason and Cronquist,1963 and Radford and others, 1968):

Picea - spruce, among the species of spruce, most are northern species except *P. rubens* Sarg., which is found in the mountains of North

Carolina and Tennessee; spruce is one of two "cold climate" taxa identified by Groot et al.(1995) in their comprehensive analysis of environments of deposition of Tertiary and Quaternary strata of the U.S. Middle Atlantic Coastal Plain (the other genus was *Abies* sp., fir).

Tsuga - hemlock, the two identified species [*T. canadensis* (L.) Carr. and *T. caroliniana* Engelm.] both occur south into the mountains of Georgia

Cyrilla - ti-ti, common in the Southeast, occurring north into southeastern Virginia

Gordonia- loblolly bay, found on the coastal plain in Florida, Georgia, Alabama, and Mississippi

There are at least three hypotheses that could explain these concurrent appearances of the pollen of northern and southern taxa: 1) Some of the warm climate taxa were reworked from older sediments (Eocene or Miocene?). The reworking hypothesis seems unlikely because no distinctive Eocene pollen were found in the Boatright samples; 2) Some pollen may represent long distance transport from distant sources. However, *Gordonia* is insect pollinated and its pollen is unlikely to have been wind transported. The relatively small amounts of spruce and hemlock could have been carried to the *Gordonia - Taxodium* swamp from far away, but the abundant pollen of alder argues for its local presence at the site of deposition; 3) The ranges of the northern and southern plants may have overlapped at the time of deposition. The climate, on average, was not too cold for *Gordonia* and was not too warm for *Tsuga, Picea,* and *Alnus*. *Nyssa* and *Taxodium*, with their relatively broad climatic tolerances were essentially unaffected by the climate conditions that existed at the time of deposition.

We favor the third hypothesis. This is based upon the reasoning that the dynamics of pollen deposition among the genera in question make this the simplest explanation for the mix of taxa found. There is additional evidence from other sites in the Southeast that supports this point of view. Early reports, such as those of Whitehead (1963) revealed the presence of northern species in ancient deposits from the Southeast. Cofer and Manker (1983) reported "northern-spruce seed-cones" with an age of 21,300 +/- 400 years BP from a site near Andersonville, in southwestern Georgia. Watts (1970, 1973) reported *Picea* pollen in cores of sediment from northwestern Georgia. Those samples were accompanied by only minor, or trace amounts of *Tsuga* and *Alnus*, however, and there was, overall, little evidence of a cold climate flora.

A fairly comprehensive analysis of spruce-dominated samples collected from the Tunica Hills, in Louisiana/Mississippi, is presented by Jackson and Givens (1994). Wood, cones, and pollen of a proposed new, but extinct southern species or subspecies of *Picea* were recovered from sediments that had accumulated in the Tunica Hills between 17, 530 and 25, 250 years ago. The contemporaneity of spruce and hardwoods (such as oak) at that site is unquestioned, though the assemblage of taxa is different from that of the Boatright deposit.

ORIGIN OF THE WOOD-BEARING CLAY

The origin of the log-jam at the Boatright Mine is another problem. The possibility that the accumulation of wood was the remnants of an ancient beaver dam or lodge did not occur to us until the large, smooth, and well-faceted piece of wood, now known to be a piece of pine, was pulled from the layer of clay. It is, for all intents and purposes, identical to a piece of beaver-gnawed wood from an active beaver foraging ground in Brooklet, Georgia (Figure 4). Short of having fossil beaver remains, however, we are faced only with the circumstantial evidence that the wood accumulation may have been produced by beavers. We undertook a brief review of what is known about the behavior and eating habits of the beaver (*Castor canadensis* Kuhl) in order to evaluate the validity of this hypothesis.

Beaver were formerly wide spread on this continent, and have probably had a significant influence on landscapes where ever they lived. According to Nelson (1918) and Naiman and others (1988), when North America was colonized by Europeans, beavers existed in great

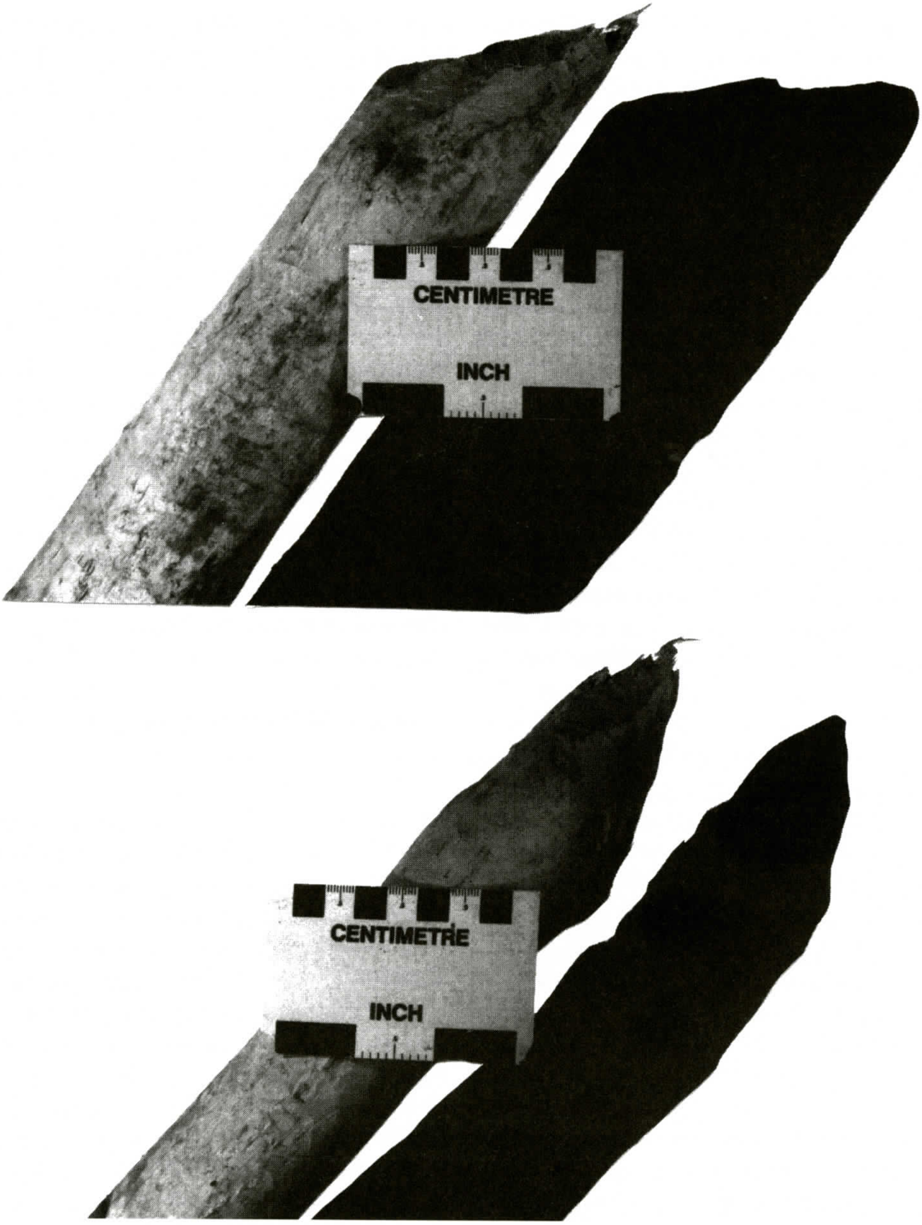

Figure 4. A piece of wood gnawed by a beaver (on the left) is shown for comparison with a piece of *Pinus* wood (on the right) from the Boatright Mine. The modern sample shows a prominent keel that results from the beaver chewing from both sides of the branch. The Boatright sample displays a similar keel. The upper photograph was taken parallel to the plane of the keel, the bottom photograph was taken perpendicular to that plane. The silhouettes of both pieces of wood display the faceted sculpturing that is commonly seen in wood that has been gnawed by beavers.

numbers from coast to coast and from near the Yukon and Mackenzie Deltas south to the mouths of the Colorado and the Rio Grande. For many years there was only one publication which related to beavers as agents of geologic change, Ruedemann and Schoonmaker (1938).

Those authors speculate upon the significance of beaver impoundments as the cause for in-filling of alluvial plains near Troy, New York. More recently, Naiman and others (1988) have described the influence that beavers have on landscape change. Summarizing the interpretations set forth in both papers, the in-filling of valleys takes place after dams have been built and sediment accumulation occurs upstream of the dam. The dam itself constitutes a significant amount of any valley-fill. Naimen and others (1988) refer to the sediment infillings as "patch bodies". According to Morgan (1868) the ground at the site of dam construction is "...usually firm and often stony; and when across the channel of a flowing stream, a hard rather than a soft bottom is preferred." According to Audubon and Bachman (1849), "The Beaver dams, where the animal is at all abundant, are built across the streams to their very head waters. Usually these dams are formed of mud, mosses, small stones, and branches of trees cut about three feet in length and from seven to twelve inches round. The bark of the trees in all cases being taken off for winter provender, before the sticks are carried away to make up the dam." Cook (1940), in documenting the history of a beaver colony on the Grit Plateau in Rensselaer County, New York, noted that the beaver built a dam "...4 feet high in the center and 100 feet long. Part of the wood was dead and fallen material, gathered along the banks: the remainder was new-cut aspen and alder. Numbers of stones and the usual coating of mud were applied to the upstream face."

One further point relative to beaver dam deposits relates to the prominent layer of iron oxides (limonite and goethite) that lay immediately beneath the thickest accumulation of clay and wood. Luza (1969) conducted an extensive survey of bog iron (iron oxide) deposits in the Black Hills of South Dakota. The bog iron ores are located primarily within the valleys associated with the higher peaks in the north-central Black Hills. Luza notes that plant remains, including wood and leaves are common within some of the consolidated bog iron deposits, and mosses and leaves are sometimes recognizable among the clastic and limonitic components of the oxide accumulations. Most, if not all of the bog iron beds represent secondary accumulations of iron oxides that were eroded from older strata and redeposited where conditions were favorable. In reference to the Long Draw bog iron deposit Luza observes that "The soluble and suspended iron is being deposited in an area where the drainage has ponded behind present and relic beaver dams." It seems quite plausible that the iron oxide layer at the Boatright locality had a similar history of formation. The iron-rich soils on the hillsides surrounding the beaver pond would have produced abundant ferruginous stream bottom sediments. When the stream was impounded, the clays accumulated behind the dam, were later altered to limonite/goethite, and were eventually covered by the dam itself. It is also possible that the organic material in the dam itself actually lead to chemical reactions that resulted in the generation of the limonite and goethite.

DIETARY PREFERENCES OF BEAVERS

Many authors indicate that beavers use a variety of deciduous trees and shrubs for food and lodge or dam construction (Schwartz and Schwartz,1959; Warren,1927; Shadle and Austin,1939; Naiman and others,1988). The sole presence of cypress and pine wood from the Boatright Mine prompts the question, Will beaver use conifer wood for construction or consumption? Cahalane (1947) notes that sometimes beaver will eat pines, cedar, spruce, fir and hemlock by choice.

Finally, it is well known that beavers create underwater food stores. Hall and Kelson (1959) mention that beavers use branches for winter food and that the branches are sunk in the deeper parts of the pond and anchored for later use. Morgan (1868) describes the animals carrying brush into their ponds to create compacted piles which are anchored to the substrate. Cahalane (1947) asserts that "Because many fall-cut logs would not waterlog and sink before being frozen in the ice, the beaver has to tow them to the winter pantry in the bottom of the pond. Here it either rams them fast into the mud, or piles stones on them." The small twigs we found which were preserved some distance away from the main mass of wood, and which are now known to include pieces of *Taxodium* root, are proposed to have been placed where they were found, perpendicular to the bedding in the sediments, as the beaver were creating a cache of food for the winter. The animals' preference for cypress might be questioned, particularly if alder was present, but several characteristics of the cypress root tissue might have lead to its being preferred as a food supply. For one thing, the root wood is softer than that of the branches, and would have been easier to harvest and consume. Additionally, the roots would have been accessible without leaving the water. What may be more important is that root wood contains more nutritious starchy photosynthates per unit volume than does stem or branch wood (Panshin and de Zeeuw, 1980); thus it would be a superior food supply. There is also more parenchyma tissue in the root/knee tissues than is found in stems or branches. This suggests greater nutrient storage capacity, and, therefore, a more attractive meal from the herbivore's point of view.

SUMMARY AND CONCLUSIONS

A review of the general characteristics of a deposit of wood-bearing clay that was discovered at the Boatright Mine, near Deepstep, Georgia, leads to the following conclusions:

1. Wood was identified as *Pinus* and *Taxodium* sp.

2. Radiocarbon analysis of wood shows it to be more than 47,740 years old.

3. Pollen recovered from three woody clay samples was derived from 39 taxa of trees, shrubs, and herbaceous plants; two types of algal cysts were present. The dominant pollen indicate the presence of *Pinus*, *Taxodium*, *Alnus*, and *Quercus* at the time of sediment accumulation. Additional genera include *Picea*, *Tsuga*, *Nyssa*, and *Gordonia*. A mix of warm and cool climate taxa characterized the site.

4. The abundance of branches with no bark lying parallel or nearly parallel with bedding, and the abundance of bevelled or faceted ends on the wood fragments suggest that the deposit is a lodge or a dam.

5. Small branch segments with bevelled ends that were standing perpendicular to the bedding plane of sediments are believed to be remnants of food caches stored by the ancient beavers.

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THE BLACK CAT GOLD VEIN: CHARLOTTE BELT, MECKLENBURG COUNTY, NORTH CAROLINA

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ABSTRACT

The Black Cat gold vein, a small but representative gold-bearing quartz vein of the Charlotte gold belt, was recently exposed in quarrying operations that have been correlated with the historic Black Cat prospect. A field and ore mineralogy investigation of this occurrence was undertaken to examine the style of gold mineralization that helped North Carolina lead the nation in gold production in the early to mid-1800's. The newly exposed quartz vein varies from 10 to 20 cm in thickness, crosscuts metagranodiorite and silicified metavolcanics, and can be followed more than 100 meters. The vein is oriented N70°W, dips steeply to the NE, and is located approximately 300 meters to the southwest of pits and trenches historically assigned to the Black Cat prospect. There is a thin selvage zone a few millimeters in thickness within both the metagranodiorite and metavolcanics that consists of calcite, pyrite and white mica.

Gold mineralization occurs in disseminated polycrystalline pyrite aggregates, up to several centimeters in size that have been partially altered to limonite. Ore microscope studies indicate that these pyrite aggregates contain small amounts of chalcopyrite, hematite, magnetite, calcite, covellite and native gold. Fire assays of typical samples of non-pyritic quartz yielded values below detection for gold. Fire assays of an approximately 99% pyrite concentrate, collected from an old pit, yielded 5.529 Troy ounces of gold per ton, confirming that the gold is associated with the pyrite. Microprobe analysis indicates the first generation grains of gold ranging in size from 1-10 micrometers precipitated in pyrite and consisted of an average 95.8 weight percent gold with an average 4.3 weight percent silver, and traces of copper and mercury. The second generation of gold (5-20 micrometers in size) filled fractures and boundaries in the pyrite and averaged approximately 90.3 weight percent gold. Silver was more abundant in this generation (averaging 9.65 weight percent), and traces of copper and mercury. Gold mineralization at the Black Cat prospect was multiphased, with an earlier, gold-rich event precipitated in pyrite followed by a later silver-enhanced event filling fractures and boundaries in association with pyrite. To our knowledge this is the first report of two periods of gold mineralization in Charlotte belt gold veins. Multiple periods of gold mineralization have been reported in gold veins to the east in the Carolina slate belt. Although this vein occurrence is not economic, it does provide some insights into precious metal mineralization in the Charlotte belt.

INTRODUCTION

Gold was first discovered in North Carolina in 1799 when young Conrad Reed found a nugget in Little Meadow Creek in what is now Stanley County. This discovery sparked the first

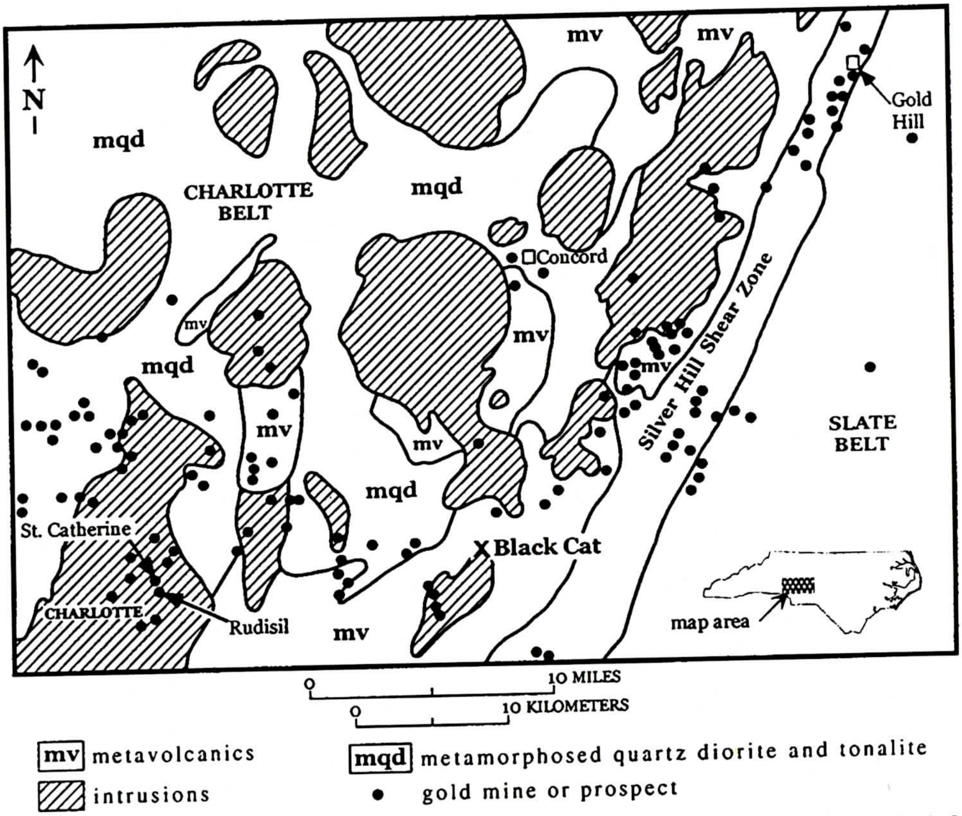

Figure 1. Generalized geologic map showing location of Black Cat vein to the regional geologic belts, intrusives, and the location of mines and prospect pits. (Geology modified from Goldsmith and others,1988 and locations of mines and prospects from Pardee and Park, 1948.)

gold rush in the United States. Reports of commercial gold recovery from placers began in 1804, but it was not until 1825 that the gold-bearing quartz vein lode deposits, from which the placers had been derived, were located and exploited (Pardee and Park, 1948; Carpenter, 1972). Many of these discoveries were centered around the city of Charlotte, and the gold produced from these operations were responsible for Charlotte's early growth into a municipality that included one of the first federal mints in the United States at Mint Hill. Many of the early exploited deposits were mined out, as miners could only work the upper oxidized portions of the vein above the water table. Many locations have been lost or filled with soil or other debris and little of the original ore material has been preserved. Many of the early gold workings were poorly documented in terms of location and production history and the Black Cat Mine is among them.

The name of the Black Cat Mine appears to have been first recorded on the map of North Carolina gold localities by Pardee and Park (1948, Plate 22), and later in Carpenter's (1972) description of gold production in North Carolina. A diligent search of the mining records and archives in Charlotte has failed to produce any additional information and the United States Geological Survey's files did not have the Black Cat listed. Nevertheless, there is evidence of at least 15 excavation sites, some as much as 5 meters in depth and 10 meters in length, in the area of study, evidencing the expenditure of considerable effort in search of gold. On the basis of the location given by Pardee and Park (1948) we are using the name Black Cat for the newly exposed vein that most likely correlates

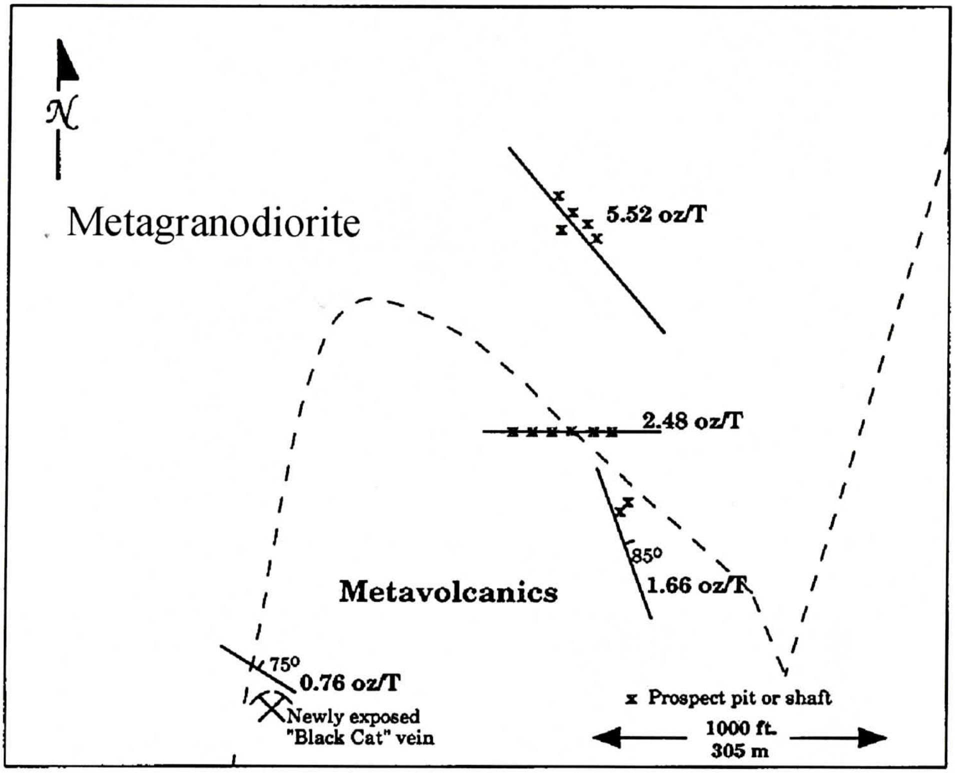

Figure 2. Generalized geologic map and some gold fire assay values of pyrite and/or limonite concentrates from the Black Cat veins. Note the southwestern value is from the recently exposed vein and those to the east and northeast are the older prospect pits and trenches.

with the historical workings just to the east indicated in Park and Pardee. The period of excavation of the many pits in the vicinity of the Black Cat is not known, but it is likely that they would date from the period shortly after gold was discovered in the Charlotte belt, as gold seekers panned virtually every stream and excavated every quartz vein that could be located. Carpenter (1972) reports that the St. Catherine Mine, lying to the west within the city limits of Charlotte, opened prior to 1826 (Figure 1). The nearby Rudisil Mine was the site of gold discovery in 1829 and went on to become one of the largest producers in the State. The gold mineralization in both of these mines occurred in quartz veins that carried pyrite and some chalcopyrite. Our observations of the geology and ore petrology of the Black Cat are consistent with the descriptions of gold-bearing quartz veins elsewhere in the North Carolina portion of the Charlotte and Carolina slate belts. They provide insights into this style of mineralization as well as increasing our knowledge of the historical gold mining operations in this region.

We have been fortunate that modern mining excavations exposed a 10-20 cm thick massive quartz vein. This vein, now covered again on private property, lies approximately 300 meters to the southwest of approximately 15 old prospect pits identified as the Black Cat Mine (Figure 1).

GENERAL GEOLOGY

This occurrence is located a few kilometers west of the Silver Hill shear zone on the eastern edge of the Charlotte belt (Figure 1). The Charlotte belt described by Goldsmith and others (1988) consists of metamorphosed plutonic rocks and metavolcanic rocks, and few

Figure 3. (A) Euhedral crystal of magnetite and lath of hematite surrounded by pyrite. (Width of field = 0.8mm.) (B) Cluster of magnetite crystals surrounded by pyrite. Hematite lamellae have formed along some (111) planes in the magnetite, but it is not possible to determine when the oxidation occurred. (Width of field = 0.8 mm.)

metasedimentary rocks. The age of the metavolcanics may correlate with the 600-700 m.y. Carolina slate belt rocks to the east and the metamorphosed felsic to mafic intrusives vary in age from approximately 520 m.y. to as young as 280 m.y. (Goldsmith and others, 1988). The age of the metagranodiorite in the Black Cat area, listed by the Goldsmith and others map (1988), ranges from Silurian to Devonian age.

Host rocks in the quarry area are metagranodiorite and silicified felsic metavolcanics. The metagranodiorite is composed mainly of pla-

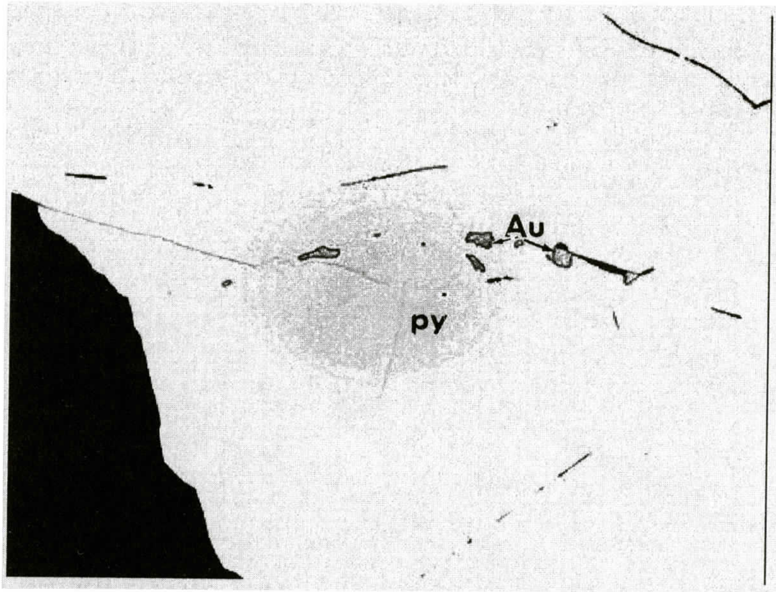

Figure 4. The first generation of gold containing about 3.5-5 weight percent silver occurs as small elongate grains completely isolated within pyrite. (Width of field = 0.4 mm.)

gioclase, quartz, hornblende and chlorite, with trace amounts of epidote and magnetite. The fine-grained silicified felsic metavolcanic rocks may have originally been tuffs. One sample consisted of quartz, plagioclase, chlorite, epidote and magnetite. The newly exposed quartz vein varies from 10 to 20 cm in thickness and cuts across the silicified metavolcanics and the metagranodiorite with a continuous exposure of more than 100 meters (Figure 2). It strikes approximately N70°W and dips approximately 75° to the northeast. There is a thin selvage, a few millimeters thick, where the vein is in contact with the metagranodiorite and metavolcanics containing fine-grained pyrite, calcite and white mica.

The northeast workings consist of three groups of prospect pits and trenches (original Black Cat?), some as deep as 5 meters, and are located approximately 300 meters northeast of the newly exposed vein (Figure 2). Exposures of quartz veins in these workings suggest multiple vein sets with individual veins measuring up to 0.5 meters in thickness. The quartz veins exposed in these older pits consist of milky white cryptocrystalline quartz. The pyrite occurs as centimeter-sized anhedral aggregates that are irregularly distributed throughout the quartz and are commonly weathered to limonite. The newly exposed vein is similar in mineralogy to those exposed in the older pits and trenches.

ORE MINERALOGY

The ores of the Black Cat are very typical of "gold-quartz veins" that occur in the Charlotte belt and slate belt (Pardee and Park, 1948; Laney, 1910; Ford, 1981). The Black Cat veins consists of milky white cryptocrystalline quartz, minor calcite and irregularly dispersed anhedral aggregates of pyrite, containing the gold that has a thin selvage zone in the host rocks. The thin alteration zone in the host rock consists of fine-grained pyrite, calcite and white mica. Polycrystalline aggregates of pyrite occur irregularly dispersed within the quartz with no apparent regard to geometry or host rock. Polished sections of pyrite aggregates reveal the presence of minor amounts of scattered crystals of magnetite and laths of hematite (Figure 3), and minor chalcopyrite and trace gold. Supergene covellite rims the chalcopyrite and weath-

Table 1. Electron microprobe analyses of gold grains in pyrite concentrates from the Black Cat prospect. Analyses were conducted at Virginia Tech using a Cameca SX-50 microprobe operating at 15Kv and 40 nanoamps. All in weight percent. Pure gold, silver, copper, and silver-antimony-sulfide ($HgSb_4S_8$) were used as standards.

Sample # and Point	Au	Ag	Hg	Cu	Total
2654 a-1	95.82	4.18	0.07	0	100.07
2654 a-2	95.50	4.38	0	0.18	100.05
2654 a-3	95.46	4.39	0.17	0.01	100.03
2654 a-4	95.95	4.05	0.11	0.06	100.17
2654 a-5	96.14	4.34	0	0.07	100.56
2656 a-1	94.73	4.79	0.32	0.34	100.18
2656 a-2	95.55	4.63	0.03	0.04	100.24
2657 a-1	94.90	5.10	0.06	0.19	100.25
2657 a-2	95.19	4.81	0	0.16	100.16
2657 a-3	95.67	4.68	0.11	0	100.47
2657 a-4	95.74	4.66	0	0.15	100.55
2657 b-1	96.40	3.60	0	0.31	100.31
2657 b-2	96.47	3.53	0.03	0.24	100.27
2657 b-3	96.52	3.88	0	0.30	100.71
2657 b-4	96.94	3.84	0	0.06	100.84
2657 b-5	96.53	3.62	0	0.15	100.3
Average	**95.83**	**4.28**	**0.05**	**0.14**	
2654 b-1	90.49	9.51	0.1	0.01	100.11
2654 b-2	90.42	9.58	0	0.12	100.12
2654 b-3	91.04	8.96	0	0.05	100.05
2654 b-4	90.54	9.45	0	0.27	100.26
2656 a-1	90.22	10.10	0	0	100.32
2656 a-2	90.09	10.27	0.11	0.11	100.59
2656 a-3	88.63	10.33	0	0.27	99.23
2658-1	90.43	9.04	0	0.15	99.62
2658-2	89.97	10.03	0.06	0.14	100.2
2658-3	90.04	9.88	0.08	0.04	100.04
2658-4	90.30	9.69	0.28	0.08	100.35
2658-5	90.40	9.61	0	0.08	100.09
Average	**90.33**	**9.65**	**0.05**	**0.1**	

ering of magnetite has occurred along the (111) planes. Weathering has caused considerable alteration of pyrite to limonite. Minor amounts of calcite occur in the quartz as gangue.

Gold in the Black Cat samples occurred within, or in association with, the pyrite. This is demonstrated by fire assaying of selected vein samples and by electron microscopy analyses and ore petrography. There appears to be two distinct generations of gold in terms of mode of occurrence and in composition. The first generation occurs as 1-10 micron sized grains disseminated within the pyrite (Figure 4) and contains 3.5-5 weight percent silver (Table 1). The second generation has somewhat larger (5-20 micron) grains that occur along fractures in the pyrite or along the margins of pyrite grains (Figure 5; Table 1) and contains 9-10 weight

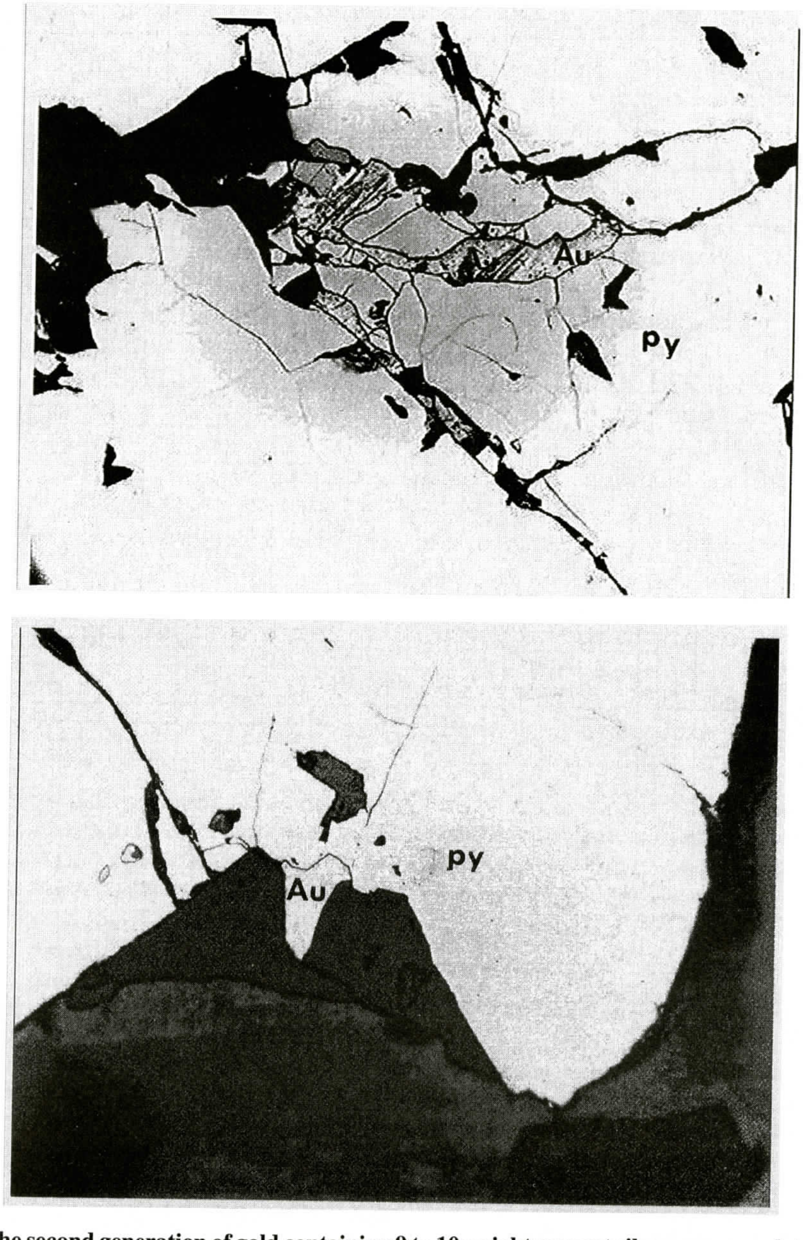

Figure 5. The second generation of gold containing 9 to 10 weight percent silver, occurs as late in fillings in fractures in pyrite as shown in (A) or as isolated grains at the margins of the pyrite as shown in (B). (Width of field of both images is 0.4 mm.)

percent silver. The microprobe analyses are plotted on a gold - silver - copper + mercury ternary diagram (Figure 6) and show the distinct separation of composition between the two generations of the gold. Texturally, the first generation of gold appears to have coprecipitated with the pyrite, whereas the second-generation solutions post-dated pyrite formation and fill fractures and crevices in the pyrite, and are enriched in silver.

Concentrates of pyrite and pyrite-limonite concentrates were prepared for fire assay by

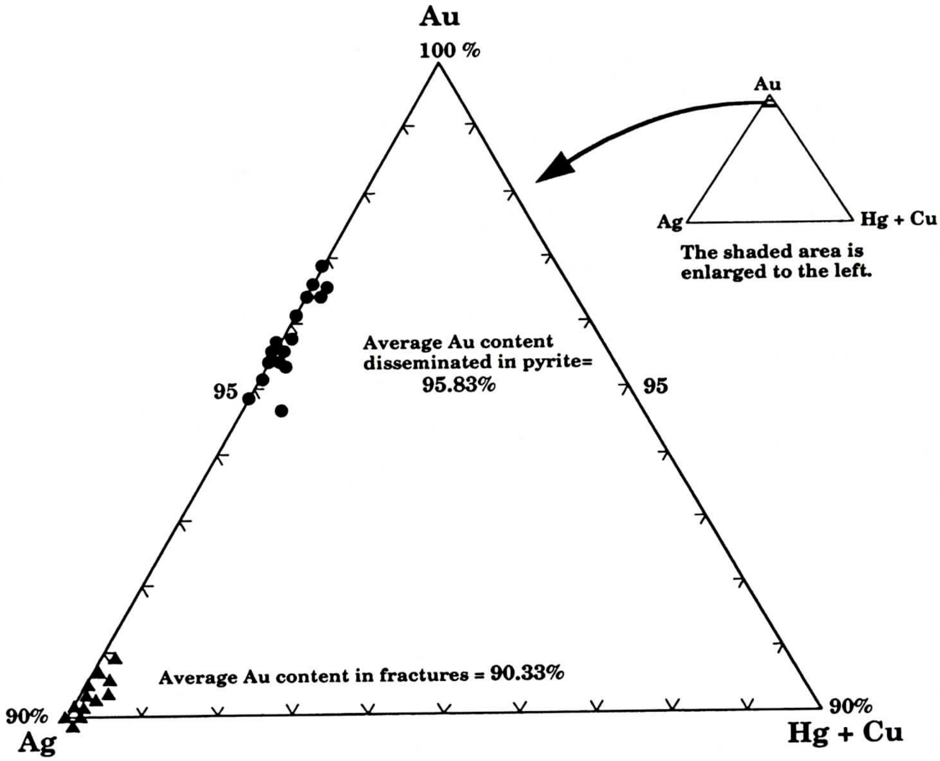

Figure 6. Ternary plot of gold - silver - mercury + copper showing two distinct groups of gold analyses. The silver-rich values are associated with the later fracture fillings and the lower silver values represent the earlier gold that coprecipitated with the quartz. (Analyses carried out using a Cameca SX-50 operated at 15Kv and 40 nanoamps using pure Au, Ag, Cu and $HgSb_4S_8$ as standards at Virginia Tech.)

Table 2. Fire assay results for samples from Black Cat veins and the relationship of gold values to pyrite content. (Fire assays by Acme Analytical Laboratories Ltd. and Activation Laboratories Ltd.) Samples 1 through 6 are from the newly exposed quartz vein samples; 6* and 7** are a limonite with some pyrite and an almost pure pyrite-rich panned concentrate, respectively, obtained from two different prospect pits from the northeast workings. Table qualifiers: ppb - parts per billion; opt - Troy ounces per ton; ND - not detected at detection limit (dl); and NA - not analyzed.

Sample Number	~ % Pyrite	Au (ppb) dl=2	Au (opt)	Ag (opt)	Pt (ppb) dl=5	Pd (ppb) dl=4
1	0	ND	<0.001	0.08	ND	ND
2	Tr	16	<0.001	NA	ND	ND
3	~10	19,359	0.565	NA	12	14
4	~30	16,108	0.470	NA	ND	ND
5	~95	35,585	1.039	NA	14	5
6*	~15	85,071	2.481	NA	NA	NA
7**	~99	189,567	5.529	0.54	NA	NA

crushing and panning vein material. The analytical results are summarized in Table 2. The assays ranged from no gold in a pure quartz sample to 5.529 Troy ounces of gold per ton in an approximate 99% pyrite-rich concentrate, prepared by panning crushed vein material in the older workings to the northeast. Silver, though present in the non-pyritic quartz vein sample at 0.08 ounces per ton, also correlates with abundant pyrite at 0.54 ounces per ton. These results support the observation that the bulk of the gold occurs in or with the pyrite. Platinum (12 to 14 parts per billion) and palladium (5 to 14 parts per billion) are also present in pyrite-rich samples. The fire assays were done by two commercial laboratories, ACME Analytical Laboratories Ltd. and ACTA Laboratories Ltd.

CONCLUSIONS

The recently exposed quartz vein associated with the Black Cat prospect has made it possible to examine the nature of the type of gold-bearing quartz veins that made North Carolina the first major gold producer in the United States. The veins in this area consist of massive quartz, with disseminated pyrite, trace amounts of calcite, and traces of other sulfides and oxides/hydroxides with small amounts of gold. The veins contain gold that was deposited during two distinct periods of mineralization. Multiple episodes of gold mineralization have also been noted farther to the east in the Carolina slate belt. Laney (1910), in the Gold Hill area to the northeast of the Black Cat prospects, noted two periods of gold mineralization and states "the copper and gold mineralizations are of two separate, and to a certain extent, distinct periods of mineralization, the one furnishing the copper with a small amount of gold and the other furnishing the gold and small percentage of copper." Ford (1981) also recognized the presence of multiple generations of gold mineralization in her study of veins and fluid inclusions from samples collected in the slate belt northeast of the Black Cat. These studies support the view that precious metal vein mineralization usually occurs in areas which have been subjected to multiple episodes of hydrothermal fluid activity. To our knowledge this is the first time multiple periods of mineralization have been documented for Charlotte belt gold veins.

Although the mineralization of the Black Cat is minor and not economic, it does afford a small view into the nature of some of the early mined gold in North Carolina.

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STRATIGRAPHIC EVIDENCE FOR NEOPROTEROZOIC-CAMBRIAN TWO-PHASE RIFTING OF SOUTHERN LAURENTIA

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ABSTRACT

U-Pb zircon dates document two separate continental rifting events of southern Laurentia: an older rift phase at 758 ± 12 Ma and a younger rift phase at 572 ± 5 to 564 ± 9 Ma. Stratigraphic relationships mapped in the southern Appalachian Blue Ridge also document diachronous phases of Laurentian rifting. Mount Rogers volcanic and clastic sedimentary rocks document the first rift stage. Upward transition in the Unicoi Formation from late synrift sedimentary rocks to a passive-margin succession records the end of the second phase of continental rifting. In northeastern Tennessee, synsedimentary faults in the lower Unicoi displace the Grenville basement-Unicoi nonconformity and further confirm the age of second stage rifting. In west-central North Carolina, the uppermost unit of the Ocoee Supergroup, the Sandsuck Formation, is interpreted as being in conformable contact with the Unicoi Formation, suggesting that at least the youngest Ocoee sedimentation is associated with the second phase of rifting. In northeastern Tennessee, the Unicoi Formation nonconformably overlies Grenville basement and oversteps onto glaciogenic sedimentary rocks of the Konnarock Formation. The Konnarock Formation unconformably overlies and truncates Mount Rogers volcanic rocks, and onlaps onto Grenville-age basement rocks. The Konnarock Formation, unconformably bracketed between the Mount Rogers (first rift phase) and Unicoi (second rift phase), was evidently deposited between the two phases of Laurentian rifting.

INTRODUCTION

In the southern Appalachian Mountains of eastern North America, Grenville basement is overlain by sedimentary and volcanic rocks interpreted as having been deposited during Neoproterozoic-Cambrian continental rifting of southern Laurentia. U-Pb zircon dates of Neoproterozoic volcanic and plutonic rocks are interpreted as representing two separate rift phases (Aleinikoff and others, 1995). The older rift phase, dated at 758 ± 12 Ma (Neoproterozoic-Sturtian), has been interpreted from dating of the Crossnore Complex and the Mount Rogers Formation. The younger rift phase, dated at 572 ± 5 to 564 ± 9 Ma (Neoproterozoic-Vendian), has been interpreted from dating of Catoctin felsic volcanic rocks and associated dikes along the northern Blue Ridge in Virginia. At least 200 m.y. separates the two rift phases. Mapping of synrift sedimentary rocks in the Blue Ridge Mountains at Laurel Bloomery, Johnson County, Tennessee (Laurel Bloomery 7.5-minute quadrangle), and in the Bald Mountains in Pisgah National Forest, Grayson County, Tennessee, and Madison County, North Carolina (Greystone 7.5-minute quadrangle) (Figure 1), provides stratigraphic evidence for two phases of Laurentian rifting (Brewer, 1997).

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GEOLOGIC SETTING AT LAUREL BLOOMERY AND BALD MOUNTAIN STUDY AREAS

The village of Laurel Bloomery, Tennessee,

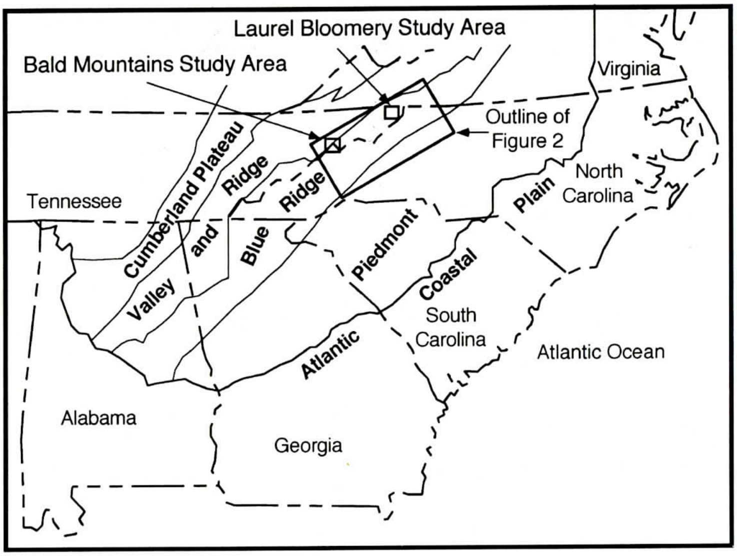

Figure 1. Map showing location of study areas in the Blue Ridge physiographic province, southern Appalachian Mountains (modified from Hatcher and others, 1989). Squares show locations of study areas.

and the Bald Mountains of Tennessee and North Carolina are located in the Blue Ridge-Piedmont thrust complex. Northwestward-directed late Paleozoic translation of the Blue Ridge-Piedmont thrust complex transported Grenvillian basement, Crossnore Complex, and synrift and postrift strata (Hatcher and others, 1989). Laurel Bloomery is within the Shady Valley thrust sheet (Stony Creek syncline) of the Blue Ridge-Piedmont thrust complex (Figure 2). The Bald Mountains study area is within the Buffalo Mountain thrust sheet (Figure 2). The Shady

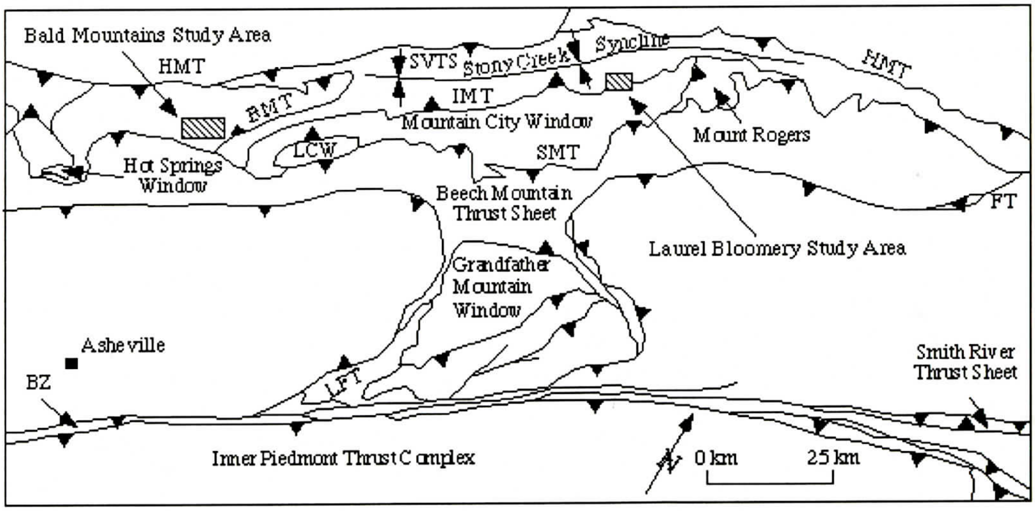

Figure 2. Tectonic map of the region around Laurel Bloomery, Tennessee, and Bald Mountains, Tennessee/North Carolina, study areas (modified from Boyer and Elliott, 1982). Thrust faults are shown with barbs on hanging wall (HMT: Holston Mountain thrust; SVTS: Shady Valley thrust sheet; IMT: Iron Mountain thrust; SMT: Stone Mountain thrust; BMT: Buffalo Mountain thrust; FT: Fries thrust; LFT: Linville Falls thrust; LCW: Limestone Cove window; BZ: Brevard fault zone).

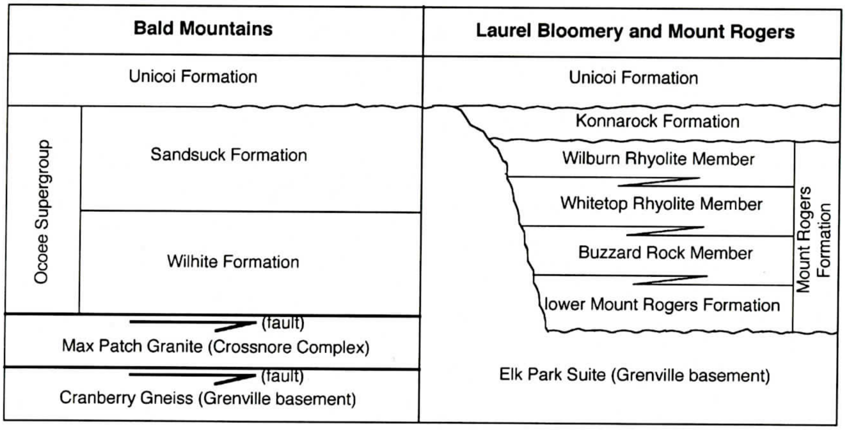

Figure 3. Generalized stratigraphic columns of the Proterozoic crystalline basement and the Neoproterozoic and Cambrian sedimentary and volcanic cover sequence in the Bald Mountains and Laurel Bloomery study areas.

Valley thrust sheet (Stony Creek syncline) is bound on the northwest by the Holston Mountain thrust fault and on the southeast by the Iron Mountain thrust fault (Figure 2) (Rankin and others, 1972). The Iron Mountain thrust fault extends northeastward and southwestward to intersect the Stone Mountain fault, framing the Mountain City window (Figure 2). The Holston Mountain and Stone Mountain thrust faults are regional faults that extend from the Laurel Bloomery area southwestward to the Buffalo Mountain thrust sheet (Figure 2). The Holston Mountain thrust fault bounds the Buffalo Mountain thrust sheet on the northwest, and the Stone Mountain thrust fault bounds the Buffalo Mountain thrust sheet on the southeast (Figure 2) (Shekarchi, 1959).

LITHOLOGIC UNITS AT LAUREL BLOOMERY AND BALD MOUNTAIN STUDY AREAS

Proterozoic Basement

Mesoproterozoic crystalline basement rocks at Laurel Bloomery and in the Bald Mountains are interpreted as Laurentian continental crust that was deformed by and/or emplaced during the Grenvillian orogeny.

U-Pb zircon (Tilton and others, 1960; Davis and others, 1962; Rankin and others, 1972), Rb-Sr whole rock (Fullagar and Odom, 1973; Odom and Fullagar, 1984), and ion microprobe U-Pb zircon (Miller and others, 1998) analyses of the crystalline rocks in the Blue Ridge yield a 1.26 Ga to 1.0 Ga age range. The Mesoproterozoic basement has been mapped as the Cranberry Gneiss and the Elk Park Plutonic Suite (Figure 3) (Keith, 1903, 1904; Rodgers, 1953; King and Ferguson, 1960; Rankin, 1970; Bryant and Reed, 1970; Rankin and others, 1972).

Crossnore Complex

Granitic plutonic and associated bimodal volcanic rocks have been mapped as the Crossnore Complex (Rankin, 1970; Rankin and others, 1972). Within the Crossnore Complex is the Mount Rogers Formation, a sedimentary and volcanic rock accumulation overlying the plutonic rocks of the Crossnore Complex (Rankin, 1967, 1976, 1993; Rankin and others, 1969, 1972). The Crossnore Complex can be roughly divided into three plutonic units (the Beech, Brown Mountain, and Max Patch granites) and three volcanic units in the Mount Rogers Formation (the Buzzard Rock Member, Whitetop Rhyolite Member, and Wilburn Rhyolite Member) (Figure 3) (Keith, 1904; Rankin, 1993). Non-inherited zircons were used for U-Pb dating of the Crossnore plutonic complex at 760 to 740 Ma (Su and others, 1994; Aleinikoff and others, 1995). A U-Pb date of 758 ± 12 Ma was obtained for the Crossnore volcanic rocks of the Mount Rogers Formation (Aleinikoff and others, 1995).

Konnarock Formation

Prior to 1993, the Mount Rogers Formation was divided into three parts, an unnamed lower unit, a middle rhyolite unit, and an upper diamictite and rhythmite unit (Rankin, 1967, 1972, 1993; Blondeau and Lowe, 1972; Schwab, 1976; Miller, 1986). Subsequently, the diamictite and rhythmite unit was separated from the Mount Rogers Formation and redefined as the Konnarock Formation (Figure 3) (Rankin, 1993). The age of the Konnarock Formation is constrained only by its stratigraphic position between the Mount Rogers and Unicoi Formations. No fossils have been found in the Konnarock or Mount Rogers Formations, precluding biostratigraphic age determination (Rankin, 1993).

Ocoee Supergroup

The Walden Creek Group is the youngest of three regional group-rank subdivisions of the Ocoee Supergroup. The Walden Creek Group is divided into four formations, from oldest to youngest, the Licklog, Shields, Wilhite, and Sandsuck Formations (King and others, 1958). The Wilhite and Sandsuck Formations crop out in the Bald Mountains (Figure 3), but not at Laurel Bloomery (King and Ferguson, 1960; Bearce, 1969; Brewer, 1997). The older subdivisions of the Ocoee Supergroup (Snowbird and Great Smoky Group) are not exposed in either map area.

The age of the Wilhite Formation has been debated as ranging from Neoproterozic to Late Devonian. Acritarchs (*Sphaerocongregus sp.*) found within the Wilhite Formation suggest a Neoproterozoic-Ediacaran age for the unit (Knoll and Keller, 1979; Knoll and Swett, 1987). Agglutinated foraminifers and fragments of bryozoans, ostracods, microcrinoids, and trilobites were discovered in association with carbonate olistoliths within strata mapped as the Wilhite Formation, south of the Great Smoky Mountains National Park. These fossil assemblages have been used to assign a Paleozoic (Silurian to Late Devonian-Frasnian) rather than a Neoproterozoic age to the Wilhite Formation (Unrug and Unrug, 1990; Unrug and others, 1991). The poor preservation of the microfossils raises concern about the identification, and hence age assignment, of the Wilhite fossil assemblage (Rodgers, 1991). On that basis, it has been argued that the microfossils discovered by Unrug and Unrug (1990) are not Silurian-Late Devonian in age, but rather are part of the Cambrian-Tommotian fossil assemblage. In addition to the debate about the age of the microfossils, the collecting locality may be fault-separated from other outcrops of the Wilhite Formation (Rodgers, 1991). A Neoproterozoic-Cambrian age for the Wilhite Formation agrees with previous geologic mapping and stratigraphic sections indicating that the Walden Creek Group lies stratigraphically below the Chilhowee Group.

The age of the Sandsuck Formation is currently not biostratigraphically or isotopically constrained. In the Bald Mountains, the Sandsuck Formation is interpreted as being conformably overlain by the Unicoi Formation (Brewer, 1997). The Unicoi Formation is interpreted as Neoproterozoic-Cambrian in age, thereby allowing at least a latest Neoproterozoic age for the Sandsuck Formation (Brewer, 1997).

Chilhowee Group

Stratigraphic nomenclature for the Chilhowee Group varies considerably along the Blue Ridge, but in eastern Tennessee, western North Carolina, and southern Virginia, the group is divided into the Unicoi Formation, Hampton Shale, and Erwin Formation. The Unicoi Formation is mapped at Laurel Bloomery and in the Bald Mountains (Figure 3) (King and Ferguson, 1960; Bearce, 1969; Brewer, 1997).

At Valley Forge, Virginia, within the Iron Mountain thrust sheet, the stratigraphically lowest known trace fossils, *Paleophycus*, are 191 m above the base of the Unicoi Formation

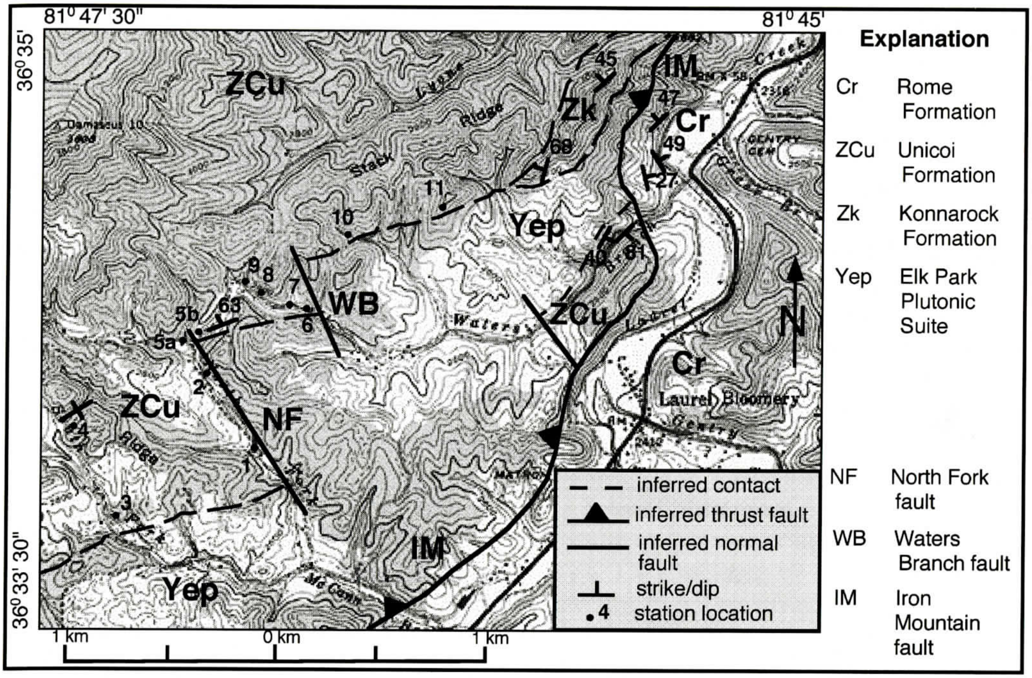

Figure 4. Geologic map of part of the Laurel Bloomery 7.5' quadrangle (Brewer, 1997; part modified from King and Ferguson, 1960).

(Cudzil and Driese, 1985, 1987). Simpson and Sundberg (1987) assigned a middle to early Tommotian age to the Unicoi Formation in Virginia on the basis of a single, lobe-shaped hyporelief identified as *Rusophycus*, although the identification of this trace fossil is equivocal. Walker (1990) used a compilation of all known trace fossils within the Unicoi Formation (*Paleophycus, Rusophycus, Planolites*) to interpret the Unicoi Formation as late Vendian to early Tommotian.

STRATIGRAPHIC RELATIONS OF SYNRIFT DEPOSITS AT LAUREL BLOOMERY, TENNESSEE

The Grenvillian Elk Park Plutonic Suite, the Neoproterozoic Konnarock Formation, and the Neoproterozoic-Cambrian Unicoi Formation are mapped in stratigraphic succession at Laurel Bloomery, Tennessee (Figure 4). The Elk Park Plutonic Suite, in this area, is a light-gray to pink, fine- to medium-grained phaneritic, gneissic quartz monzonite (Brewer, 1997). In the Shady Valley thrust sheet, northwest-dipping beds of the Unicoi Formation nonconformably overlie the Elk Park Plutonic Suite (Figure 4). Along strike to the northeast, in the same thrust sheet, the top of the Elk Park and the base of the Unicoi diverge northeastward at the southwestward pinchout of the Konnarock Formation (Figure 4) (King and Ferguson, 1960; Brewer, 1997). The contact between the Konnarock Formation and the underlying Elk Park Plutonic Suite is unconformable, as is the contact between the Konnarock Formation and the overlying Unicoi Formation (King and Ferguson, 1960; Brewer, 1997).

The Konnarock Formation in the Laurel Bloomery quadrangle is a red and gray-green, medium-grained arkosic sandstone with rounded to sub-rounded feldspar and quartz grains, and interbeds of gray-green, schistose mudstone (Brewer, 1997). In the vicinity of Mount Rogers, Virginia, the Konnarock Formation consists of massive and bedded diamictite containing a matrix-supported conglomerate, rhythmite varves with dropstones, and massive

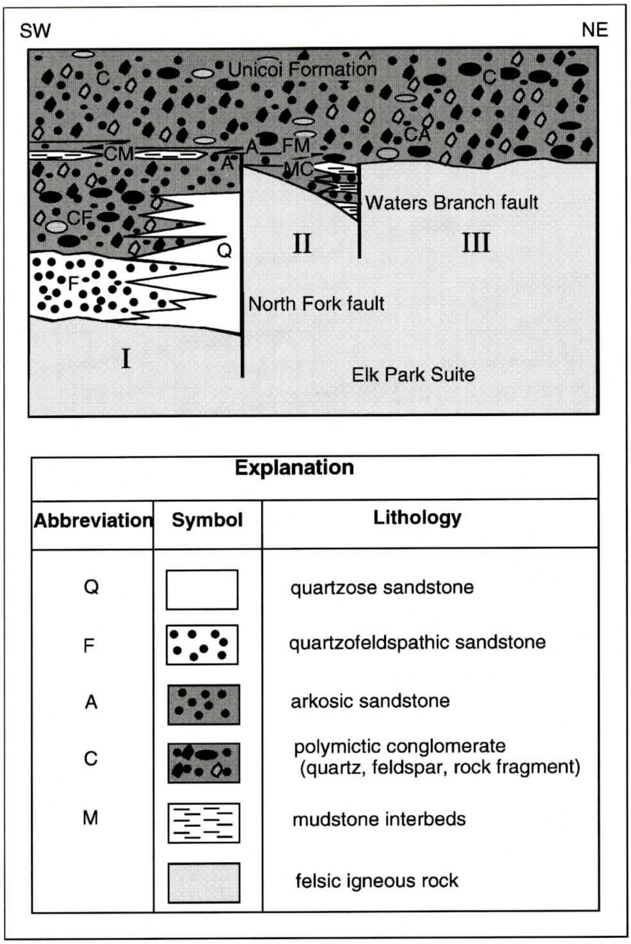

Figure 5. Schematic cross section showing facies variations within the Unicoi Formation in relation to the North Fork and Waters Branch faults.

argillite and arkose (Rankin, 1993; Rankin and others, 1994; Miller, 1994). The matrix-supported conglomerate contains sand- to boulder-size clasts of unweathered Grenvillian granite, Mount Rogers rhyolite and basalt, argillite, and arkose (Rankin, 1993; Rankin and others, 1994; Miller, 1994). The Konnarock Formation is interpreted as a glaciolacustrine sequence (Rankin, 1969; Miller, 1986).

The Konnarock Formation unconformably overlies the Mount Rogers Formation at Mount Rogers, Virginia, and nonconformably overlaps onto the Elk Park Plutonic Suite at Laurel Bloomery, Tennessee (King and Ferguson, 1960; Brewer, 1997). Along its entire outcrop length, the Konnarock Formation unconformably underlies the Unicoi Formation. These cross-cutting relationships, along with the ages of the Grenvillian basement and the Unicoi Formation, bracket an estimated age of the Konnarock Formation as between approximately 770 Ma and 545 Ma. Two glacial episodes are recognized in the Neoproterozoic rock record at 780 Ma to 720 Ma (Sturtian glaciation) and 610 Ma to 590 Ma (Varanger glaciation) (Eyles, 1993). The relative age of the Konnarock Formation is within the time intervals for both of those glacial episodes.

The lower part of the Unicoi Formation is a conglomerate and pebbly sandstone that grades upward into coarse-grained arkosic sandstones. The Unicoi conglomerate contains rounded pebbles (5 to 25 mm diameter) of quartz, alkali feldspar, and granitic rock fragments from the underlying Elk Park Plutonic Suite (Brewer, 1997). Basalt flows mapped in the Laurel Bloomery area (King and Ferguson, 1960) were extruded during the deposition of the Unicoi Formation. The basalt is amygdaloidal, and is in lenticular pods as much as 30 m thick. Irregular structures within the basalt may be pillow structures (King and Ferguson, 1960; Simpson and Eriksson, 1989; Walker and others, 1994). These basalt flows are mapped along strike regionally and correlated to the 564 ± 9 to 572 ± 5 Ma Catoctin Formation (Simpson and Eriksson, 1989; Aleinikoff and others, 1995).

TIMING OF SYNRIFT FAULTING AT LAUREL BLOOMERY, TENNESSEE

Mapping at Laurel Bloomery, Tennessee, documents two steeply dipping faults, the North Fork and the Waters Branch faults, that displace the Elk Park-Unicoi contact (Figure 4) (King and Ferguson, 1960; Brewer, 1997). Sedimentary facies within the Unicoi Formation differ across the basement blocks separated by these faults (Figures 4 and 5). Mapping of lateral and upward facies changes within the Unicoi Formation, with respect to the location of the North Fork and Waters Branch faults, constrains the timing of latest fault movement (Brewer, 1997).

On the southwestern, downthrown side of the North Fork fault, the basal Unicoi Formation consists of white, coarse-grained, well-sorted, sub-rounded to rounded, quartzose sandstone (Figures 4 and 5, block I, stations 1 and 2). The quartzose sandstone proximal to the North Fork fault grades laterally away from the fault into an olive to light-green, medium- to coarse-grained, moderately sorted, well-rounded, medium-bedded, quartzofeldspathic sandstone. The quartzofeldspathic sandstone coarsens up section into a light-medium-brown, medium- to coarse-grained, poorly sorted, sub-rounded, quartz- and feldspar-clast (4 to 12 mm diameter) conglomeratic sandstone (Figures 4 and 5, block I, stations 3 and 4). The quartzose sandstone proximal to the North Fork fault grades upward into a red-gray, medium- to coarse-grained, well-sorted, well-rounded, arkosic sandstone interbedded with quartz-, feldspar-, and basement-clast (12 to 25 mm diameter) conglomerate (Figures 4 and 5, block I, station 5a). On the northeastern, upthrown side of the North Fork fault, which is also the downthrown block of the Waters Branch fault, the basal Unicoi Formation proximal to the North Fork fault is a light- to medium-brown-gray, fine-grained, rounded, moderately sorted, arkosic sandstone (Figures 4 and 5, block II, station 5b) that grades laterally into a brown-red, well-rounded, moderately sorted, quartz-clast (4 mm diameter) conglomerate supported by an arkosic sandstone matrix, proximal to the Waters Branch fault (Figures 4 and 5, block II, stations 6 and 7). Interbedded with the conglomerate are red-brown, fissile shales. The conglomerate-shale units grade upward into light-brown-gray, coarse-grained, well-rounded, moderately to well-sorted, quartzofeldspathic sandstone also interbedded with red-brown shale (Figures 4 and 5, block II, stations 8 and 9). On the northeastern, upthrown side of the Waters Branch fault, the basal Unicoi Formation consists of a polymictic conglomerate containing quartz, feldspar, and Elk Park-rock-fragment clasts (25 mm diameter) interbedded with coarse-grained, arkosic sandstone with a reddish-brown matrix (Figures 4 and 5, block III, stations 10 and 11) (Brewer, 1997). Overlapping this succession of laterally variable sedimentary rocks are laterally continuous Unicoi conglomeratic rocks that are not displaced by either the North Fork or Waters Branch faults (Brewer, 1997).

Fine- to coarse-grained, compositionally and texturally mature to submature sandstones and mudstones proximal to the North Fork and Waters Branch faults, lateral and upward facies changes into compositionally immature, coarser grained sandstones and conglomerates distal from the faults, and overlap of conglomeratic rocks over the basin-fill facies and associated faults is evidence for syndepositional movement of the North Fork and Waters Branch faults (Brewer, 1997). Simple-shear angular rotation of the down-dropped fault blocks during normal fault movement displaces the axis of the fault basin toward the fault plane. Rotation of

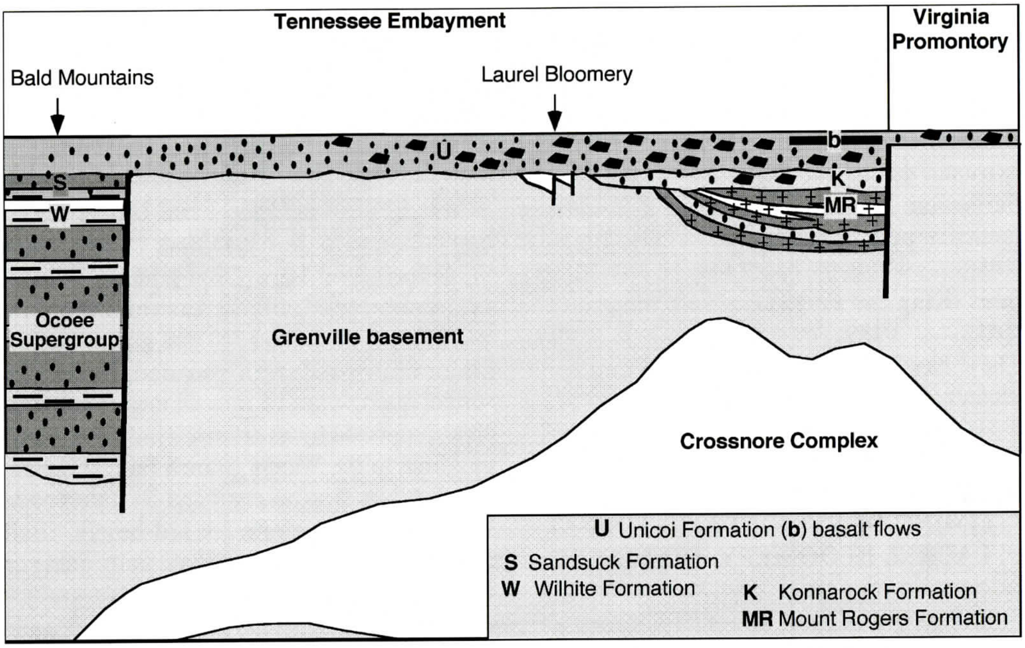

Figure 6. Schematic cross section showing stratigraphic and structural relationships of synrift rocks between Proterozoic crystalline basement and post-rift rocks of the upper Unicoi Formation (modified from Thomas, 1991; and Walker and others, 1994).

fault blocks shifts interbasinal, longitudinal fluvial drainage patterns, and results in shifting of a stream toward the active fault plane (Blair and Bilodeau, 1988). Shifting of longitudinal drainage patterns and deposition of fluvial sediments are primary responses to tectonic activity in fault basins, and alluvial-fan sedimentation is a secondary response to tectonic activity (Blair and Bilodeau, 1988). Coarse-grained alluvial-fan sedimentation is delayed until significant weathering and erosion of freshly exposed, uplifted, fault blocks has occurred. The result of such a system is initial deposition of finer grained, fluvial sediments proximal to active faults in tectonic basins with lateral and upward facies changes into coarser grained alluvial deposits, as characterizes the fault-basin fill mapped at Laurel Bloomery (Brewer, 1997).

The North Fork and Waters Branch faults, and the associated synrift basins, are a subset of the larger scale Blue Ridge rift system (Thomas, 1991) and represent a small-scale version of the model presented by Blair and Bilodeau (1988) (Figure 6). The unconformity between Grenvillian Elk Park and Neoproterozoic-Cambrian Unicoi at Laurel Bloomery suggests long-term weathering of the Elk Park Suite prior to Unicoi deposition. This is in contrast to the extrusion of Mount Rogers volcanics onto Elk Park igneous rocks and subsequent deposition of the glaciolacustrine Konnarock Formation during the time represented by the Elk Park-Unicoi hiatus. Weathering during the time of the Elk Park-Unicoi hiatus provided quartz and clay for initial erosion and deposition into the North Fork and Waters Branch fault basins during initial brittle fault movement (Brewer, 1997). Mature quartzose sediments initially deposited in the down-dropped fault blocks were subsequently covered by submature arkosic sediments and polymictic conglomerates derived from nearby uplifted terranes, such as Grenvillian basement blocks and the Mount Rogers volcanic center (Figure 6). Other examples of synsedimentary faults associated with Laurentian rifting include a northwest-striking fault zone that displaces the contact of Grenville basement with synrift Fauquier Formation in

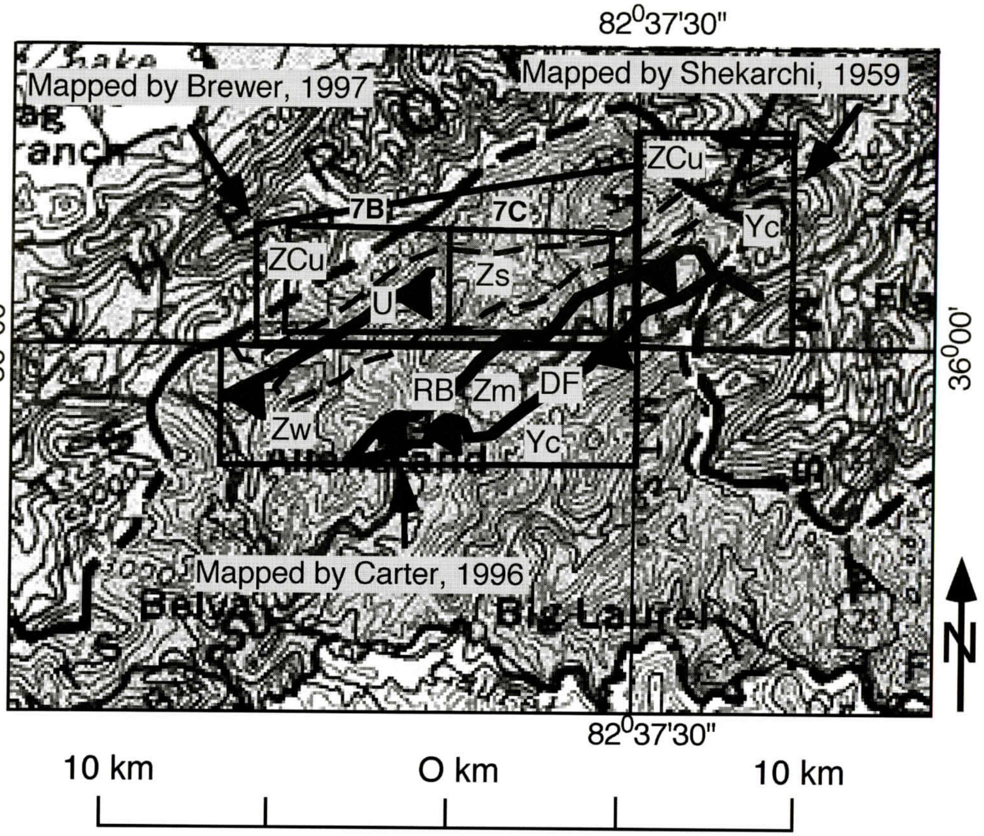

Figure 7. Geologic map of the Bald Mountains study area. A: Regional geologic map. B: Geologic map of the southwestern part of the Greystone 7.5' quadrangle (Brewer, 1997). C: Geologic map of the southeastern part of the Greystone 7.5' quadrangle (Brewer, 1997).

Fauquier County, Virginia (Espenshade, 1986), and a northeast-striking fault that displaces the contact of Grenville basement with Longarm Quartzite (Ocoee Supergroup) in Haywood County, North Carolina (Montes and Hatcher, 1999).

SYNRIFT DEPOSITS IN THE BALD MOUNTAINS, TENNESSEE AND NORTH CAROLINA

In the Bald Mountains, geologic mapping records the Grenvillian Cranberry Gneiss, Neoproterozoic Max Patch Granite, Wilhite Formation, Sandsuck Formation, and Neoproterozoic-Early Cambrian Unicoi Formation (Figure 7) (Shekarchi, 1959; Bearce, 1966,

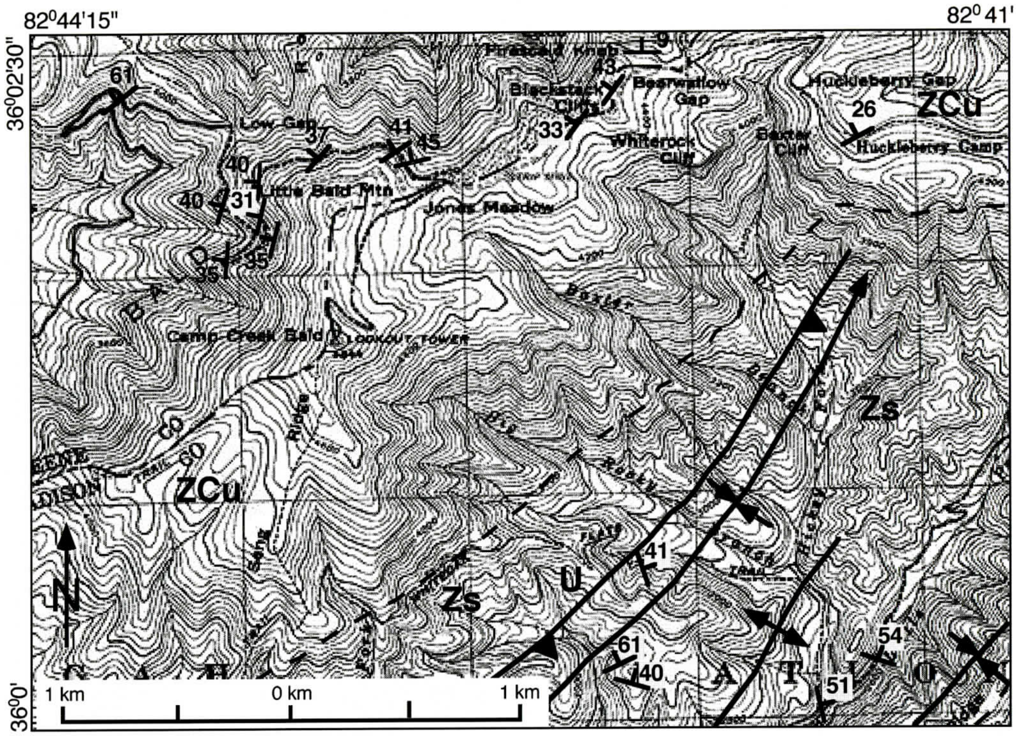

Figure 7B.

1969; Carter, 1996; Brewer, 1997). The Cranberry Gneiss is a gray to light-medium-brown, medium-grained, porphyroblastic, granite-gneiss with a quartz and alkali-feldspar composition and a chlorite matrix (Brewer, 1997). The Max Patch Granite is a gray-brown to green-pink, medium-grained phaneritic granite containing quartz, alkali feldspar, and biotite (Brewer, 1997).

The Wilhite Formation is divided into two members: the lower Dixon Mountain Member and upper Yellow Breeches Member (King and Ferguson, 1960). The Dixon Mountain Member of the Wilhite Formation is a blue-gray to medium-gray to light-green, banded, micaceous, sandy siltstone that contains carbonate laminations and is locally interbedded with mud-chip-bearing, light-gray quartzose sandstone (Brewer, 1997). The Yellow Breeches Member is a sandy and conglomeratic limestone and dolomite. The carbonates are interbedded with dull-green to gray, argillaceous, feldspathic sandstones (King and Ferguson, 1960). The carbonate rocks are poorly exposed in the Greystone 7.5-minute quadrangle, but have been mapped farther south by Carter (1996) in the contiguous White Rock 7.5-minute quadrangle as beds that pinch out in the Greystone quadrangle (Figure 7A).

The Sandsuck Formation is divided into two units: a lower unit of conglomerate and mudstone, interbedded with quartzofeldspathic and quartzose sandstones; and an upper unit composed primarily of mudstone that is interbedded with arkosic sandstones (Brewer, 1997). The conglomerate is light-gray to light-medium-brown and moderately sorted, and it contains subangular to rounded quartz, plagioclase feldspar, and sedimentary rock fragments (1.5 to 40 mm diameter). The conglomerate also contains rip-up clasts of gray mudstone (30 to 310 mm diameter). The quartzofeldspathic sandstones are light-brown to pink, medium- to coarse-grained, well-sorted, and well-rounded; the

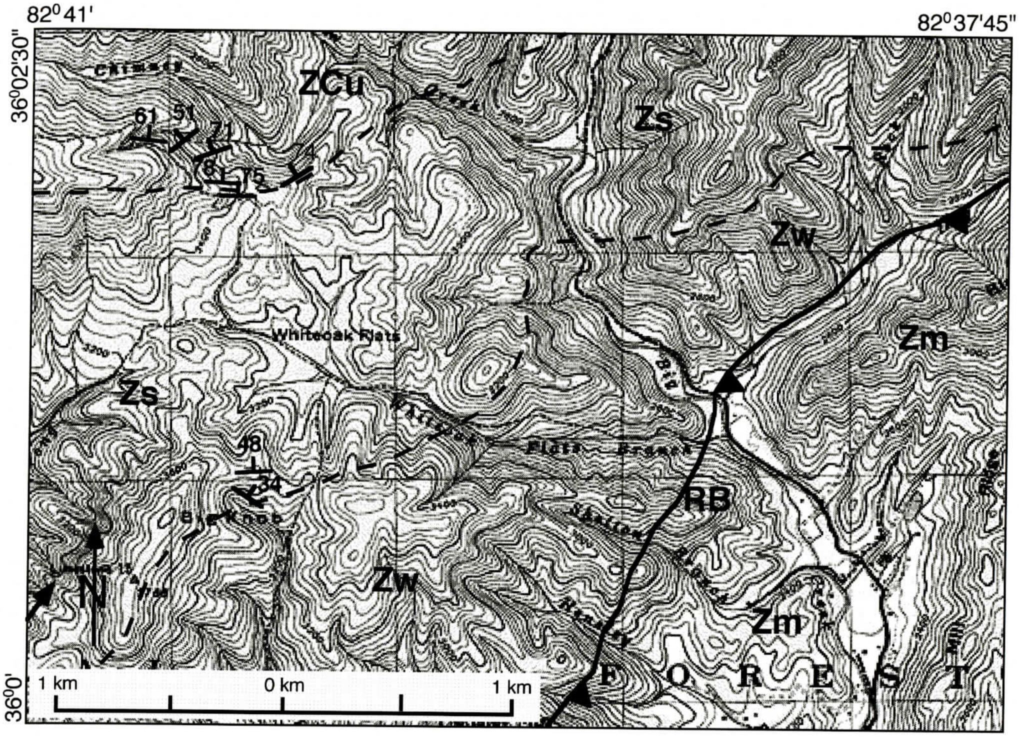

Figure 7C.

sandstones contain quartz, plagioclase feldspar, and rock fragments. The quartzose sandstones are white to gray, massively bedded and fine-grained; the quartz grains are sub-rounded. The mudstone is light-gray to dark-gray and contains feldspar- and quartz-sand laminations.

The basal units of the Unicoi Formation in the Bald Mountains (Figures 7B and 7C) grade up section from fine-grained arkosic sandstones, interbedded with light-brown to gray-green mudstones to medium-grained, medium- to massive-bedded, cross-bedded quartzose sandstones (Brewer, 1997). The conglomeratic units that comprise the basal Unicoi Formation at Laurel Bloomery are not recognized in the Greystone quadrangle (Brewer, 1997). Previous work has yielded differing descriptions of the Unicoi Formation in the Bald Mountains. Oriel (1950) and Shekarchi (1959) described the basal Unicoi Formation in the Bald Mountains as a quartz-pebble conglomerate containing feldspar, granite, and gneiss clasts. This description is identical to that of the Unicoi Formation at Laurel Bloomery, but units of this description were not identified in the Bald Mountains (Brewer, 1997). The basal beds of the Unicoi Formation in the Greystone quadrangle are more consistent with the description by King and others (1958) in their report on the geology of the Great Smoky Mountains National Park, southwest of the Bald Mountains. King and others (1958) described the Unicoi Formation as the "first persistent beds of arkose and quartzite." These arkoses and quartzites, mapped herein as lower Unicoi, however, have been previously interpreted as part of the Snowbird Group (Bearce, 1969). Part of the succession previously mapped as the Snowbird Group in this area, however, has been remapped by Carter (1996) as the Wilhite Formation of the Walden Creek Group, on the basis of the presence of carbonate units. The identification of the Wilhite Formation demands re-interpretation of all of the previously mapped Snowbird Group in this area. Regionally, the Snowbird Group is shown to lie nonconformably on the Grenville basement and beneath the Walden Creek Group, which is mapped stratigraphically beneath the Unicoi Formation (King and others, 1958; Brewer, 1997; Montes and Hatcher, 1999). No evidence was encountered in the field to account for a possible tectonic emplacement of the Snowbird Group above the Wilhite Formation. Therefore, in the context of the description of the Unicoi Formation by King and others (1958), and the mapping of the Wilhite Formation by Carter (1996), the oldest persistent arkoses and quartzose sandstones are reinterpreted as the basal units of the Unicoi Formation lying in stratigraphic succession above the Wilhite and Sandsuck Formations (Brewer, 1997).

The basal Unicoi facies varies regionally along strike from conglomerate at Laurel Bloomery to quartzose and arkosic sandstones in the Bald Mountains (Brewer, 1997). An upward lithologic gradation from Sandsuck to Unicoi suggests a conformable contact of Sandsuck Formation with the overlying Unicoi Formation in the Bald Mountains. The Unicoi Formation has been interpreted as being Neoproterozoic-Cambrian in age, allowing a minimum age of latest Neoproterozoic for the Sandsuck Formation (Brewer, 1997).

CONCLUSIONS

U-Pb isotopic analyses of the Blue Ridge crystalline basement indicate that the Grenvillian orogenic event culminated at approximately 1.0 Ga (Tilton and others, 1960; Davis and others, 1962; Rankin and others, 1972; Bartholomew, 1984). The southern Laurentian margin was deformed by continental extension approximately 200 to 250 m.y. after the Grenvillian orogeny (Aleinikoff and others, 1995). Laurentian rifting in the Appalachians is currently interpreted, through U-Pb zircon dating of felsic volcanic rocks of the Crossnore Complex and the Catoctin Formation, as having occurred in at least two phases: an aborted phase at 758 ± 12 Ma (Neoproterozoic-Sturtian) and a second rift phase from 572 ± 5 to 564 ± 9 Ma (Neoproterozoic-Vendian) (Aleinikoff and others, 1995). The second rift phase is interpreted as leading to continental separation and the opening of the Iapetos Ocean (Bird and Dewey, 1970; Rankin, 1976; Thomas, 1977, 1991; Rankin and others, 1989).

Crossnore Complex rocks emplaced within and extruded upon the Grenvillian crystalline basement are dated at 758 ± 12 Ma using U-Pb isotopes (Su and others, 1994; Aleinikoff and others, 1995). The intrusion of the Crossnore Complex marks the beginning of the first phase of Laurentian rifting (Aleinikoff and others, 1995). Distribution of Crossnore Complex rocks solely in the southern Appalachians documents the first Laurentian rift phase as occurring exclusively along the southern Laurentian margin (Aleinikoff and others, 1995).

A nonconformable contact of Mount Rogers Formation with Grenville basement and the presence of clasts of Grenvillian basement and Crossnore plutonic rocks in the basal Mount Rogers sedimentary rocks serve as evidence for uplift and erosion of the Grenvillian basement and the Crossnore plutonic rocks. Uplift and erosion of Grenvillian basement and Crossnore plutonic rocks must have occurred during the later stages of the first Laurentian rift phase, after crystallization of Crossnore igneous rocks. Thick accumulations of the Mount Rogers Formation are interpreted as resulting from subsidence of uplifted terranes to form rift basins (Rankin, 1975, 1976, 1993; Thomas, 1977; Keller, 1980; Rast and Kohles, 1986).

Catoctin volcanic rocks (564 ± 9 Ma), as well as basalt lava flows within the basal Unicoi Formation, document the second phase of Laurentian rifting (Aleinikoff and others, 1995) in the southern Appalachians. Distribution of Catoctin volcanic rocks indicates that the second phase of Laurentian rifting extended along the entire continental margin (Aleinikoff and others, 1995).

Deposition of quartzose and arkosic sandstones and conglomerates in the basal Unicoi Formation at Laurel Bloomery, and conglomerates and arkosic sandstones interbedded with massive mudstones in the Sandsuck Formation in the Bald Mountains indicate renewed uplift and erosion of Grenvillian basement and any overlying sedimentary cover sequences, as well as the Crossnore Complex that intruded the Grenvillian basement. Deposition of the Unicoi Formation was affected locally by movement along faults mapped at Laurel Bloomery, Tennessee. The faults displace only the lowermost part of the Unicoi Formation at Laurel Bloomery. The North Fork and Waters Branch faults are overlain by continuous beds of the middle and upper Unicoi conglomerates, sandstones, and mudstones, showing that fault movement ceased before the end of Unicoi deposition during the early Tommotian.

The nonconformable deposition of Konnarock diamictites upon Elk Park granites and Crossnore rhyolites indicates Neoproterozoic glaciation along the southern Laurentian margin (Blondeau and Lowe, 1972; Schwab, 1976; Rankin, 1993; Rankin and others, 1994; Miller, 1986, 1994). The sedimentological relationships of the Konnarock Formation with the underlying Crossnore rhyolites and the overlying Unicoi conglomerates constrain the age of glaciation to between approximately 770 Ma and, at youngest, 545 Ma.

Late in the second phase of Laurentian rifting, Unicoi deposition varied from quartz-pebble conglomerates, and quartzose and arkosic sandstones at Laurel Bloomery, Tennessee, to quartzose and arkosic sandstones, and mudstones in the Bald Mountains, Tennessee/North Carolina. The conglomerates and quartzose and arkosic sandstones of the Unicoi Formation at Laurel Bloomery may reflect sediment deposition in an uplifted, subaerial environment. The lack of conglomeratic rocks and the presence of cross-bedded quartzose and arkosic sandstones interbedded with mudstones in the Bald Mountains are interpreted to indicate sediment deposited in a topographically lower setting than that at Laurel Bloomery. Laurel Bloomery, although in the Tennessee embayment of the Laurentian rifted margin, is near the Virginia promontory (Figure 6), which is interpreted as an upper-plate rift margin (Thomas, 1993). The Bald Mountains are within the Tennessee embayment (Figure 6), which is interpreted as a lower-plate rift margin (Thomas, 1993). Upper-plate margins are modeled as having higher topographic elevation than lower-plate margins; and, hence, rocks deposited proximal to upper-plate margins generally contain more abundant lithic clasts, and are less well sorted and less well rounded than sediments deposited distally from upper-plate margins (Walker and others, 1994). Within the Tennessee embayment, the Bald Mountains are spatially farther from the Virginia promontory than is the Laurel Bloomery area, and facies variations in the lower Unicoi between Laurel Bloomery and the Bald Mountains (Figure 6) (Brewer, 1997) are consistent with their respective tectonic setting.

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